NASA Contractor Report 4312

Design and Evaluation of Candidate Pressure Distribution and Air Data System Tile Penetration for the Aeroassist Flight Experiment

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Design and Evaluation of Candidate Pressure Distribution and Air Data System Tile Penetration for the Aeroassist Flight Experiment

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PREFACE

This report summarizes the most significant development activities in support of the AFE PD/ADS. The major accomplishments are presented in the main body of this report while the more detailed information is in the appendices. This pressure measurement system was conceived at LaRC and tested at JSC and LaRC.

The development of this system proved to be successful, leading to fabrication of the PD/ADS assembly for incorporation into the AFE aerobrake.

Acknowledgment is given to the following principals who had responsibility for managing their respective areas of activity:

- Paul M. Siemers III, AFESIO Science Integration, co-principal investigator and PD/ADS concept developer NASA/LaRC.

- James D. Milhoan, Technical Test Director of the ARMSEF test facility at NASA/JSC.

- Craig S. Cleckner, Aerospace Engineer Thermal Analysis Section, NASA/LaRC.

- Lora J. Atkins, Aerospace Engineer Structure and Mechanics Division, NASA/JSC.

- William S. Lassiter, Head Engineering Analysis Branch and Report Editor, NASA/LaRC.

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LIST OF ACRONYMS

A/B..................Aero-Brake

AFE..................Aeroassist Flight Experiment

ARMSEF..............Atmospheric Re-entry Materials and Structures Evaluation Facility

BTU..................British Thermal Unit

C/V..................Carrier Vehicle

CVCM................Collected Volatile Condensable Material

F....................Fahrenheit

FB...................Full Bond

GE...................General Electric

Grms................Gravity force, Root Mean Square

GSFC................Goddard Space Flight Center

HDBK................Hand Book

Hz...................Hertz

IBS..................Integrated Boom System

JSC..................Johnson Space Center

KSC..................Kennedy Space Center

LaRC................Langley Research Center

MSFC................Marshall Space Flight Center

MWatt...............Mega Watt

NASA................National Aeronautics and Space Administration

NO...................Number

NRP..................NASA Reference Publication

PCF..................Pounds per Cubic Foot

PD/ADS..............Pressure Data/Air Data System

LIST OF ACRONYMS

PSF..................Pounds per Square Foot

RCG..................Reaction Cured Glass

REV..................Revision

RQMT.................Requirement

RSI..................Re-usable Surface Insulation

RTV..................Room Temperature Vulcanizing elastomeric

SEADS................Shuttle Entry Air Data System

SILTS................Shuttle Infrared Leeside Temperature Sensor

SINDA................Systems Improved Numerical Differencing Analyzer

SIP..................Strain Isolation Pad

SRD..................System Requirement Document

STS..................Space Transportation System

TEOS.................TetraEthyl-OrthoSilicate

TML..................Total Mass Loss

TPS..................Thermal Protection System

DESIGN AND EVALUATION OF CANDIDATE PRESSURE DISTRIBUTION AND AIR DATA SYSTEM TILE PENETRATION FOR THE AEROASSIST FLIGHT EXPERIMENT.

SUMMARY

The Pressure Data/Air Data System (PD/ADS) pressure port development consisted of a series of analyses and tests of candidate pressure sensing concepts that were expected to be capable of providing accurate pressure data acquisition for the Aeroassist Flight Experiment (AFE). Significant activities, findings, and discussions are found in subsequent sections of this report. Vibro-acoustic, aero-thermal, and structural testing of the pressure port designs have been completed at the Johnson Space Center (JSC) vibration laboratory and the 10 MWatt Atmospheric Re-entry Materials and Structures Evaluation Facility (ARMSEF) and at the Langley Research Center (LaRC) structures laboratory. The designs utilized two different bonding techniques which were evaluated for compatibility with LI-900, FRCI-12, and LI-2200 insulation tiles at surface temperatures up to 2300 degrees F, 2800 degrees F, and 2900 degrees F, respectively. The vibro-acoustical, thermal, and structural performances of the pressure ports were found to be significantly within the design limits for all cases.

Two failure mode tests were conducted at a tile surface temperature of 2900 degrees F to evaluate the effects of a broken quartz pressure port or loose pressure line. This

failure mode proved to be benign relative to Thermal Protection System (TPS) performance and substructure heating. Although the outboard tip of the fully bonded quartz pressure tube melted slightly due to the ingestion of hot gases, the melted quartz material fused with the Reaction Cured Glass (RCG) coating, preventing the low emittance substrate from being exposed. The partially bonded quartz pressure port i.e. the Room Temperature Vulcanizing elastomeric (RTV) bonded tube maintained its general geometry and did not fuse with the RCG coating.

Another follow on test was performed to determine the effects of a fractured RCG coating over the area of the pressure tube tip. This failure mode was also confirmed to be benign for FRCI-12 insulation tile, where the surface temperature was 2700 degrees F.

INTRODUCTION

The AFE spacecraft is a blunt body test vehicle the mission of which is to verify the concept of reducing the velocity of a vehicle returning to earth from geosynchroneous orbit or from a lunar mission by using atmospheric drag or aero-braking. The AFE spacecraft incorporates eleven science and technology experiments many of which depend on accurate surface pressure measurements for their success. The concept of obtaining pressure measurements through the TPS has been accomplished on the Space Transportation System (STS) by inserting pressure ports into the TPS at selected locations and connecting them to pressure transducers. Measurements on the STS have been made at temperatures up to 2520 degrees F as documented in the NASA contractor report CR-166044 for Shuttle Entry Air Data System (SEADS). The AFE TPS surface temperature could reach 2900 degrees F. Therefore, in order to meet the challenge of the higher temperatures, a design effort was initiated to investigate several concepts for pressure ports in a high temperature environment. Conceptually the pressure tubes must penetrate through the TPS to the RCG coating on the tile surfaces. Pressure ports that are so constructed will be subjected to the severe heating environments experienced by the TPS. These pressure ports must maintain their geometry at the RCG inlet orifices to the quartz tubes for accurate data to be acquired and must be thermally compatible with the TPS to prevent localized overheating.

The PD/ADS tile penetration design that was developed is a flush orifice installed in the RCG coated TPS covering the AFE Aerobrake (A/B). Conceived at NASA/LaRC, it provides a turbulence free orifice for accurate pressure measurement.

The PD/ADS A/B pressure port array layout is presented in figure 1 and the pressure measurement system is schematically depicted in figure 2.

The candidate pressure port concept that was developed for testing and evaluation consists of a quartz pressure tube embedded in the TPS terminating slightly behind the RCG. The quartz tube connects, beneath the aerobrake surface, to a Viton tube that connects to a pressure transducer. Additional hardware consists of: tube clamps, that fasten the Viton tube to the quartz tube; anti-strain clamps, that prevent breaking of the quartz tube as a result of sudden pulls on the connected Viton tube; and a protective shield, that prevents damage to the quartz tube, and a pressure transducer as shown in figures 2 and 3. This port concept was subjected to a series of tests including vibro-acoustic, aero-thermal and structural to demonstrate its feasibility. The most critical tests, the aero-thermal tests were conducted at the JSC 10 MWatt atmospheric re-entry materials and structures evaluation facility (ARMSEF) to demonstrate the thermal and structural stability of the concept. Pre-test photos of the arc-jet test articles are shown in figures 4 through 6 and descriptions of the individual test activities and results are detailed in subsequent sections of this report.

As a result of the success of this AFE development activity the PD/ADS pressure port penetration concept is also being considered for future Space Shuttle Orbiter pressure port replacements.

DESIGN DEVELOPMENT HISTORY

The development of the pressure port assembly and

MATERIALS SELECTION

Penetration tubes on earlier Space Shuttle pressure port designs were made of Vycor (Corning Glass), a borosilicate with a softening point of 1508 degrees F. In the AFE case, since temperatures in excess of 2900 degrees F are expected, Corning Glass fused silica 7940 (quartz) was selected. This material has a softening point of 2876 degrees F and a melting point of 3477 degrees F.

The tubing selected from the pressure port to the transducer is a Viton (MIL-R-83248A, type II, class 1) tube with 0.25-inch outside diameter and 0.062 inch-thick wall. A sample of this material was tested in an oven for two hours at a temperature of 650 degrees F with no significant distortion or blistering. This particular Viton material is listed in the NASA Reference Publication (NRP) as Viton tubing C-6412-47 and has a Total Mass Loss (TML) of 0.13% and 0.0% Collected Volatile Condensable Material (CVCM).

The high temperature ceramic adhesive used to bond the tubes to the tiles in these designs was Cotronics 989 or Aremco Ceramabond 569. Although tests of the high temperature ceramic bonds showed minor local tile structure slumping at the bond interface, there was no indication of structural failure and all specimen passed vibrational, aero-thermal, and structural tests. The other adhesive utilized in this development program was General Electric RTV 560, the baseline adhesive for TPS installation.

The TPS tiles used in this program were made of LI-900, FRCI-12, and LI-2200 with a baseline Reaction Cured Glass (RCG) coating.

PENETRATION ASSEMBLY DEVELOPMENT

DESIGN EVOLUTION

The design goal was to create a system that would obtain accurate pressure data in the AFE's harsh thermal and vibro-acoustic environment without causing tile or RCG coating damage. Previous pressure port designs were reviewed and found to be unacceptable primarily due to fracturing at the tube RCG coating interface during vibro-acoustic tests.

A pressure port was designed that bonds the quartz tube to the Reusable Surface Insulation (RSI) by means of GE RTV 560 adhesive, but isolated from the RCG coating thus eliminating the RCG cracking problem. A .001 to .003 inch gap between the tip of the quartz pressure port and the bottom of the RCG coating was incorporated into the AFE design. The quartz pressure port was secured to the TPS by counter boring the tile and forming a flange around the middle of the pressure port, and bonding the two together. (see figures 8 through 10).

Various design concepts with the above mentioned features were developed, some of which are shown in figures associated components began in September, 1988 with the initial goal of defining concepts that would provide accurate pressure measurements while preventing excessive heatflow into the A/B, Carrier Vehicle (C/V), and the Integrated Boom System (IBS). Additional study goals were:

1) Identification and selection of materials capable of surviving the AFE mission and maintaining structural integrity.
2) Develop a concept that would minimize or prevent gas leakage through the TPS and Strain Isolation Pad (SIP).
3) Protect the RCG coating from damage during the harsh mission vibro-acoustic and aero-thermal environment.
4) Provide protection to the vehicle and its subsystems in case of quartz tube failure.

The port design requirement for survivability was to 2900 degrees F maximum surface temperature in the aerobrake stagnation region. This temperature corresponds to the 4100 LBS vehicle , 3 sigma trajectory, as documented in JSC memorandum FM 4(89-46) titled "AFE 4100 LBS Optimized Reference Trajectory" by M. Tigges.

Several pressure port configurations that would satisfy the design requirements were conceived. The simplest design, a single component quartz tube, was selected because it minimized parts and required less procedures, therefore, producing fewer failure modes.

Variations of this basic concept were tested in three types of TPS materials in the ARMSEF facility at JSC: LI-900 at 2300 degrees F; FRCI-12 at 2700 degrees F and 2800 degrees F; and LI-2200 at 2900 degrees F.

The pressure port variations consisted of three different bonding methods being considered to join the quartz tubes (Corning Fused Silica 7940) to the TPS: a high temperature ceramic adhesive/RTV full bond, and a half bond, both coupled with RTV at the flange, and a RTV partial bond, as shown in figure 7. All bonding methods were vibro-acoustically tested, but in the aero-thermal and structure tests only the full bond and the partial bond were actually tested.

Vibration and aero-thermal tests were conducted at JSC to verify that structural and thermal integrity is maintained in simulated AFE environments and no damage to any components of the pressure port assembly occurs, namely the RCG coating.

Structural tests were conducted at LaRC to verify that no damage occurred to the TPS structure when a tube is accidentally broken by bending, twisting, and/or pulling.

A system concept evaluation was also conducted which consisted of a thermal analysis of the penetration assembly and a pressure response analysis of the total pressure measurement system. System concept feasibility was thus demonstrated through a combination of tests and analyses.

11 through 13. These concepts were shown in tests to perform in more severe vibro-acoustic environments than anticipated by the AFE.

PRESSURE PORT ORIFICE FABRICATION AND ASSEMBLY

TILE CORING

The fabrication procedure developed requires finished, RCG coated, and TetraEthyl-OrthoSilicate (TEOS) densified tiles and is as follows:

1) The RCG coated side of the tile was bonded to a steel plate using wax as an adhesive
2) The uncoated side of the tile was surface ground to the thickness specified for the tile at the designated location on the aerobrake or the aftbody.
3) The steel plate was then removed by melting the wax and bonded to a glass plate again using wax.
4) The tile was cored, with a diamond drill, to within .010 inch of the back surface of the RCG. The remaining Reusable Surface Insulation (RSI) material was carefully removed. Preferably coolant should not be used, but where coolant was required for this operation water only was utilized.
5) When coolant was used, the tile was vacuum baked to a temperature of 2250 degrees F to remove the coolant from the porous RSI.

6) The RCG coating was then bored through the cored hole
with a diamond tipped drill bit approximately 0.03 inches into the glass backing plate, using a steady flow of TFE freon coolant for drill cooling.

7) The glass plate and wax were removed and the entire tile was cleaned with acetone.

8) The distance from the bottom of the counter bore to the inside surface of the RCG coating was measured and recorded as indicated in figure 8.

QUARTZ PRESSURE PORT FABRICATION

Quartz tubes were produced as shown in figures 9 and 10, and ground to the dimensions indicated. The pressure port lengths from the end of the pressure port to the flange were matched with the tile depth as recorded in step 8 above to within -0.001 to -0.003 inches.

TILE/QUARTZ PRESSURE PORT ASSEMBLY PROCEDURE

FULLY BONDED PRESSURE PORT

A layer of high temperature ceramic adhesive (Cotronics 989) was applied very sparingly to the upper part of the fully bonded quartz tube, keeping the tip free of the adhesive. The quartz tube was then inserted into the cored hole of the matched tile and bonded to the tile with GE RTV 560 at the pressure port flange as shown in figure 7. The assembly was cured at room temperature for eight hours.

PARTIALLY BONDED PRESSURE PORT

The partially bonded quartz tube was inserted into the cored hole of the matched tile and was bonded at the tube flange with RTV 560 and the assembly cured at room temperature for eight hours. Note: No high temperature adhesive was used. **CAUTION:** Keep mating surfaces free from adhesives, i.e., quartz tube flange and TPS counter bore surface interface.

Although a full flight pressure measurement system has not been assembled at this time, figures 2 and 3 show a recommended pressure system assembly based on the experience gained in this development program.

DESIGN VERIFICATION OBJECTIVES

VIBRO-ACOUSTIC TEST OBJECTIVE

The vibro-acoustic test objective was to verify that every component of the penetration assembly would survive the AFE vibro-acoustic load environment without damage.

AERO-THERMAL TEST OBJECTIVES

The aero-thermal test objective was conducted to verify the performance of the pressure port system in a simulated AFE high temperature environment, to verify the feasibility of all selected materials, and to obtain the data required to:

1) evaluate dimensional stability
2) evaluate quartz pressure port failure modes associated with the two pressure port bonding methods
3) determine the effects of tile failure.

STRUCTURAL TEST OBJECTIVES

The objectives of the structural tests were to obtain data that would be used to demonstrate the sufficiency of the bond and to demonstrate the tile resistance to damage in the event that the quartz pressure port was pulled, bent, or twisted from the RSI substrate. The major concern of this test program was to demonstrate that in the event an accidental tube breakage occurs, the RSI material and the RCG coating would remain intact, TPS damage could be catastrophic to the spacecraft and the experiment's design must preclude such damage. As the aero-thermal tests demonstrated, a broken tube will not jeopardize the spacecraft.

QUARTZ PRESSURE PORT FORMING TEST

This test was performed to determine the cross-sectional area change due to the 90 degree forming operation, required at selected pressure measurement locations in the BFHE booms. This change in cross-section area could effect the pressure response, and needed to be characterized.

adhesive and RTV. Test specimen 1 through 3 were fully bonded with Cotronics 989 high temperature ceramic adhesive and RTV at the flange, while test articles 4 through 6 were partially bonded at the flange with RTV, as illustrated in figure 21.

2) Pressure Port Forming Test Article (90 degree bent tube)

Twelve 90 degree bent quartz tubes were installed approximately 1.4 inches apart into a 0.9 inch thick, 6.0 by 4.0 inches RCG coated tile using the partially bond (RTV) technique as shown in figures 22.

3) Torque Test Specimen

Twelve quartz tubes were installed approximately 1.4 inches apart into a 0.9 inch thick, 6.0 by 4.0 inches RCG coated tile using the partial bond (RTV) technique. A 0.375 inch hex nut was cemented to the end of each of the protruding quartz tube as depicted in figure 23.

4) Pull Test Article

Twelve quartz tubes were installed approximately 1.4 inches apart into a 0.9 inch thick, 6.0 by 4.0 inches RCG coated tile using the partial bond (RTV) technique as shown in figure 24.

5) Formed Pressure Port (90 Degree Bent Tube) Test Article

Twenty-five tubes were built according to figure 10 and were cut normal to the tangent of the 45 degree angle subtended by the bend radius center line as shown in figure 25.

TEST FACILITIES

VIBRO-ACOUSTIC TEST FACILITY

This test program was performed at the JSC Vibration and Acoustic Test Facility on the shaker model no. 275 with a maximum output of 40 Grms.

AERO-THERMAL TEST FACILITY

This aero-thermal test program was performed in test position no. 1 of the JSC ARMSEF. This particular test position is the larger of the two shown in the artist's concept of the test facility, figure 26. Nitrogen and oxygen are stored in the high pressure tube trailers shown in this figure. A gas flow control system that has a measurement error of less than 1% is used to meter these gases into a segmented, constricted arc heater as shown in figure 27 where they mix inside a long cylindrical column to form simulated air. While traversing the length of this column, the gas mixture absorbs approximately 50% of the power dissipated by an electrical arc that is maintained along the center line of the column. The heated gas passes through a plenum and enters the test chamber through an expanding nozzle. Various nozzle configurations are available to tailor the flow

DESIGN VERIFICATION TEST ARTICLES

VIBRO-ACOUSTIC TEST ARTICLE

The test article for the vibro-acoustic tests consisted of three quartz tubes spaced approximately 2.5 inches apart installed in a 0.9 inch thick by 6.0 inches square RCG coated tile according to the procedure described in the fabrication and ssembly section. The vibration test assembly was mounted on a two inch thick by nine inch square aluminum plate utilizing SIP and RTV 560 adhesive, and using baseline AFE procedures, as illustrated in figures 14 and 15. This test article was then mounted on a shaker table.

AERO-THERMAL TEST ARTICLE

The test articles for this test program consisted of quartz pressure ports that were mounted in RCG coated 3.9 inch diameter by 0.9 inch thick disks of LI-900, FRCI-12, and LI-2200 RSI. These specimen were instrumented by JSC with thermocouples and bonded to the SIP and the aluminum skin as shown in figure 16. RTV was not applied to the inside diameter of the hole in the SIP to prevent pressure pockets when the space craft is subjected to space environment. One thermocouple was installed between the SIP and the TPS and one between the SIP and the aluminum skin. A thermocouple was also placed between the quartz tube and the Viton tube near the RTV bond. One set of test articles featured the full bond, i.e., Cotronics 989 high temperature ceramic adhesive on the upper part of the tube and GE RTV 560 adhesive around the flange. The other set featured the partial bond, i.e., RTV adhesive on the flange only, as depicted in figure 7.

The completed test assemblies, shown in figures 6 and 17, were mounted in water cooled 5 inch diameter cylindrical holders as shown in figure 18. Aluminum spacer rings were used to support the test articles and to ensure an effective gas seal at the rear of the test article. The holder instrumentation port shown in figure 8 was not sealed so the pressure behind the test article could approach the free stream pressure. This configuration permitted the maximum pressure differential to be experienced across the test article to investigate flow-through effects. The test assembly was mounted flush in the holder utilizing the above mentioned aluminum spacer as illustrated in figure 18. In this test program Viton tubing with an inside diameter of 0.125 inch and a wall thickness of 0.0625 inch was connected to the quartz tubes and routed to a pressure transducer with a .090 inch diameter copper line as shown in figure 19.

STRUCTURAL TEST ARTICLES

1) Bending Test Article (straight tube)

Six quartz pressure ports were bonded approximately 1.4 inches apart into a 0.9 inch thick, 6.0 by 4.0 inches RCG coated tile using Cotronics 989 high temperature ceramic characteristics to the test program requirements. For the purposes of this test program a conical nozzle with a 10 degree half angle and a 15 inch exit diameter was selected. The heated gas exiting from this nozzle formed a hypersonic flow field inside the test chamber where the pressure was maintained at approximately 0.20 Torr.

The test pressure is determined with a water cooled Pitot tube that is used to measure the dynamic stream impact pressure before the test assembly is inserted. The pressure port transducer was used only as an indicator to monitor possible leakage in case the Viton tubing melts or the quartz tube is damaged.

Instrumented calibration models fabricated by Lockheed Missiles and Space Corporation were used to establish test conditions prior to testing the pressure port models. The calibration models had 30 gauge type R thermocouples laid on top of the RSI material and the RCG coating was sprayed over both items and baked in an oven at a very high temperature. Figure 20 shows the complete calibration model assembly.

Two test models can be installed simultaneously inside the test chamber by mounting them on two water cooled, remotely actuated sting arms. These sting arms hold the models outside the boundary of the hypersonic flow field until steady state flow conditions have been established. While insertion time of these sting arms can be adjusted to as low as 0.1 second, it is normally set at 0.5 second to reduce the acceleration loads on the test articles. The overall test setup can be visualized by examining the cutaway view of the test chamber that is depicted in figure 28. Stream stagnation pressures are measured with a flat faced 0.5 inch diameter water cooled Pitot probe before inserting the test models to confirm that the desired pressure has been achieved.

STRUCTURAL TEST FACILITY

All structural tests were conducted at LaRC utilizing pull gauges and torque wrenches. The test articles were clamped to a work bench and the gauges or wrenches were attached to the individual tubes, as illustrated in figures 21 through 25.

TEST CONDITIONS

VIBRO-ACOUSTIC TEST CONDITIONS

The vibro-acoustic tests were conducted in accordance with the requirement specified in the AFE System Requirement Document (SRD) MSFC-RQMT-1439 and overtested as summarized in tables 1 and 2. The random vibration spectrum is shown in figure 29A, where the units on the ordinate are G^2/Hz and on the abscissa are Hz. Four test conditions were selected:

1) sinusoidal sweep @ 0.25 Gs
2) random @ 7.5 Grms

3) random @ 10 Grms

4) random @ 24 Grms.

AERO-THERMAL TEST CONDITIONS

The test temperatures were selected to be near maximum surface temperature limits of the three RSI materials under investigation. Tests were performed at surface temperatures ranging from 2300 degrees F to 2900 degrees F and stagnation pressures from 40 psf to 59 psf. An exposure time of 150 seconds was determined to be representative of the critical phase of the aero-pass heating and was used throughout this test program. The test plan is contained in Appendix A. The target test conditions and the actual test temperatures are summarized in table 3. A summary of the facility operating parameters and the arc heater/nozzle configuration used for this program are included in Appendix B for historical reference. Enthalpy values shown in this summary were determined analytically by the energy balance method.

STRUCTURAL TEST CONDITIONS

The objective was for the structural integrity of the RSI material and the RCG coating to be intact after all the tests have been performed. The following structural tests were conducted to simulate accidental damage:

1) bending test

2) pull test

3) torque test.

TEST RESULTS

VIBRATION TEST RESULTS

The vibration test results are shown graphically on figures 30 through 36. The X-axis was not tested at the 7.5 Grms level as indicated in table 1 but was overtested at 24.2 Grms. The lower and the upper curves in these graphs are the limits of the test band in which the test article data should be located, as shown in figure 29B. After the test, the specimen was dissected and visually inspected with a microscope and the following observations were made:

1) the RCG coating showed no signs of fracture or chipping.
2) the internal structure of the TPS showed no damage.
3) the quartz pressure ports were without fractures and remained solidly in the tile
4) no distortion, cracking or loosening of the RTV 560 or the high temperature ceramic adhesives was observed.

All three bonding techniques survived successfully at all vibration levels.

AERO-THERMAL TEST RESULTS

A total of eleven tests were performed in the JSC 10

MWatt ARMSEF in accordance with the program test matrix specified in table 3 to evaluate the thermal performance of two of the candidate bonding designs:

1) the full bond
2) the partial bond

The tile materials tested were:

1) LI-900
2) FRCI-12
3) LI-2200.

Serial numbers were assigned to all of the test articles upon arrival at JSC. These serial numbers incorporated the LaRC model number, a code that identified the configuration, and a sequential model number that was assigned by the test facility. For example, the test article 1-L9FB-157 indicates that this specimen was assigned the serial number 1 by LaRC, was fabricated from LI-900, was fully bonded, and was assigned the serial number 157 by JSC.

Calibration tests were performed to establish facility operating parameters before installing the test articles. Test conditions required to produce RCG surface temperatures of 2300 degrees F, 2700 degrees F, 2800 degrees F, and 2900 degrees F were defined with the arc operating at the required pressure by using a constant gas flow of 0.25 lb/sec and adjusting the arc current and the model to nozzle distance. One test article at a time was installed in the chamber to permit the test conditions to be verified with a calibration model that was mounted on the other insertion arm.

Pre-test photographs of the test articles are shown in figures 4 through 6, 17, and 37 through 41. Post-test photographs are shown in figures 42 through 60. Overall test article thickness measurements were obtained at the facility before and after the tests. These thickness measurements were obtained with deep throat Vernier calipers at five locations denoted A, B, C, D, and E as shown on each of the data sheets compiled in Appendix C. Also, surface profile scans of most of the test articles were performed after they were returned to LaRC and are included as Appendix D.

Since the pressure port test articles did not have surface thermocouples, optical pyrometers were monitored during the tests to compare the surface temperatures between the calibration model and the test article. The output of these pyrometers were recorded with corrections included for window losses and emittances of 1.0, .95, .90, .85, .80, .75, and .70. These outputs are graphically recorded in Appendix E for historical reference. The optical pyrometer used is sensitive to light emitted in the range from approximately 1000 nanometers to 2300 nanometers.

The LI-900 specimen were the first articles to be tested and after the first two tests (run numbers 903 and 904) it was discovered that the LI-900 test articles 1-LI9FB-157 and 6-L9-162 were located at 10 inches from the nozzle exit instead of the required 8 inches. The resulting surface temperatures were approximately 200 degrees F below the required 2300 degrees F. Since the test articles were visually unchanged by the exposure, they were re-tested at the desired conditions, run numbers 913 and 906, respectively.

At the end of the 150 second heating period the quartz/Viton interfaces on both LI-900 test articles had not exceeded 125 degrees F as shown in figures 61 and 62. These figures also disclose that the peak interface temperatures reached after the test articles were retracted were 232 degrees F for the fully bonded tube and 158 degrees F for the partially bonded tube. No visible changes in the geometry of the pressure port orifices were visible after these tests were completed. The pre-test and post-test thickness measurements summarized in table 4 indicated no significant shrinkage had occurred. The surface profile measurements showed a variation of 0.003 inch or less across the test specimen surfaces.

With the completion of the LI-900 tests the FRCI-12 fully and partially bonded test articles (3-F12FB-159 and 5-F12-161) were tested at the 2700 degrees F surface temperature (run numbers 907 and 908, respectively). Stagnation pressure was approximately 50 psf for both of these tests. As shown in figures 63 and 64 the temperature of the quartz tube/Viton tube interface on both test specimens did not exceed 175 degrees F at the end of the 150 second heating pulse and the peak temperatures during the cool down phase did not exceed 266 F for the fully bonded port and 297 F for the partially bonded port.

Based on visual inspection and thickness measurements (table 4), the pressure port orifices on both test articles showed no significant changes in appearance or shrinkage after exposure (significant change is considered to be in excess of 0.015 inches which is the maximum RCG coating thickness or quartz pressure port protrusion or RCG cracking). The surface profile measurements exhibited a maximum variation of 0.008 inch for the fully bonded port and 0.005 inch for the partially bonded port.

Test articles 4-F12FB-160 and 8-F12-164 were tested at the 2800 degrees F surface temperature with an approximate stagnation pressure of 51 psf (run numbers 909 and 910, respectively). The Viton tube/quartz tube interface temperature on the fully bonded port did not exceed 230 degrees F at 150 seconds while subjected to the arc-jet stream and reached a peak temperature of 351 degrees F during the cool down phase as indicated in figure 65. The profile depicted in the surface profile shows a maximum tile surface variation of 0.004 inch for the 4-F12FB- 160 test article. The Viton tube/quartz pressure port interface temperature of the partially bonded tube did not exceed 150 degrees F at 150 seconds and attained a maximum peak temperature of 250 degrees F during the soak back phase as shown in figure 66. The RCG coating over the pressure probe tip on the test article 8-F12-164 was chipped out during the removal of the water cooled holder which is shown in the photographs in figures 52 and 58. Minor shrinkage of the FRCI-12 was recorded as shown in table 4, but the port orifice appeared not to be deformed and was not protruding from the RCG coating. No profile was produced for this test run, but this specimen was re-run in a failure mode, simulating a fractured RCG coating, which is discussed later.

Test articles 7-L22-163 and 2-L22FB-158 were tested in runs 911 and 912, respectively at 2900 degrees F surface temperature and a stagnation pressure of approximately 59 psf. The Viton tube/quartz tube interface temperature for the partially bonded test article did not exceed 200 degrees F at 150 seconds and attained a peak temperature of 284 degrees F during the soak back period as shown in figure 67. The interface temperature on the fully bonded test specimen did not exceed 250 degrees F at 150 seconds and reached a peak temperature of 343 degrees F during cool down as shown in figure 68. Insignificant shrinkage of the LI-2200 insulation tiles were noted as indicated in table 4. Minor deformation around the pressure port orifice of both test models was barely visible and no protrusion of the tip of the tube through the coating, no fractures, or any other damage were observed. Profiles of these test models were not taken because these test articles were re-tested, simulating broken pressure port tubes, which will be discussed in the following paragraphs.

Following the completion of testing with the nominal configuration ports three tests were performed to evaluate what were defined to be the two most probable failure modes:

1) open ports due to a broken quartz tube or a loose pressure line
2) a broken RCG coating over the port tips.

Due to the limited number of test articles that were available the open tube failure tests were restricted to the two LI-2200 tile insulation test specimen (fully bonded and partially bonded) at the 2900 degrees F test point. The damaged coating failure test was restricted to the earlier tested FRCI-12 test article (tested at 2800 degrees F) which already had its RCG coating chipped out over the tip of the pressure tube during post test removal from the arc heater chamber.

The LI-2200 test articles were reassembled with the Viton pressure lines removed and a calorimeter plate installed in the holder to allow heating rates and temperatures behind the open port to be measured. The configuration of these failure mode test articles and the slug calorimeter plates are shown in figures 69 and 70. The calorimeter plate is a 0.0625 inch thick hexagonal aluminum plate to which two thermocouples are attached to monitor the temperature of the plate. By using the time history plots shown in figures 71 and 72 and knowing the surface area, weight, and specific heat at constant pressure of these slug calorimeter plates the conversion constant was determined to be 0.185 Btu/ft^2/degree F. The heating rate at the rear of the open pressure port can then be calculated by multiplying this constant with the slope at any point on the temperature-time history plots in figure 71 for the fully bonded LI-2200 test model and figure 72 for the partially bonded LI-2200 model. The temperature responses for both of the aluminum plates were similar and had three distinctly identifiable phases. The first thirteen seconds of these two runs was characterized by higher heating rates (1.7 and 1.2 Btu/ft^2-sec for the partially and the fully bonded test articles, respectively). Between thirteen and approximately eighty seconds the heating rate was less (0.12 and 0.13 Btu/ft^2-sec, and after eighty seconds it increased to 0.22 and 0.28 Btu/ft^2-sec, respectively). The higher heating rate present in the first thirteen seconds may have been attributable to warm gases entering the model holder vent port as the pressure equalization occurred between the model's internal cavity and the free stream. The temperatures of the 0.0625 inch thick aluminum plates did not exceed 250 degrees F for either of these two failure mode tests.

After the 150 seconds exposure to 2900 degrees F the open port orifices on both test articles were slightly melted (as shown in the photographs in figures 73 through 76 for the full bond test article). This melting was due to the additional heat absorbed from the ingestion of hot gases. The photograph in figure 73 shows the fully bonded test article in the water cooled holder after the first test run (test run no. 912). Furthermore, a concave depression approximately 0.045 inch deep and at a 0.15 inch radius from the quartz tube center line formed around the fully bonded port orifice as shown in the close-up photograph in figure 75 and the surface profile graph in Appendix D-3. No exposure of the low emittance RSI substrate was observed, because the quartz pressure ports had melted and fused to the RCG coating. In addition surface variation data were recorded and are presented in Appendix C.

The partially bonded quartz tube test article, shown in the figures 77 trough 79, melted slightly on the inside diameter. The melted material was deposited on the slug calorimeter as illustrated in figure 80. The quartz tube remained at its original position while the surrounding tile material slumped approximately 0.040 inches and formed a 0.1 inch radius (from the quartz tube center line) trench around the port orifice, as pictured in the close-up photograph in figure 78. Again, no exposure of the low emittance substrate was noticed, but RCG coating remained on top of the quartz tube as shown in figures 77 and 78. The surface variation is summarized for both articles in table 4 and the surface profile is included in Appendix D.

Test article 8-F12-164 was exposed a second time to the 2700 degrees F test point to evaluate the effects of a fractured RCG coating on a FRCI-12 tile. The Viton tube-to-quartz tube interface temperature for this test article was less than 325 degrees F at 150 seconds after insertion into the arc-jet stream and reached a peak temperature of 455 degrees F as shown in figure 81. The orifice area of the probe tip underwent very little change as evidenced by comparison of the pre-failure test photograph figure 58 and the post failure test photographs figures 82 through 84. The surface variation of the failure mode test article (Appendix C, C-5) was insignificant as the data in Appendix C indicate, and the surface profile in Appendix D, D-10 shows a deep narrow groove around the quartz tube tip. The quartz tube melted slightly on its inside diameter. The dissected test article depicted in figure 85 shows that the RCG coating melted, re-flowed, and filled the deep crevice around the quartz tube. The RCG coating also completely covered the previously exposed RSI material.

All test articles illustrated in figures 85 through 91 were dissected and inspected. Various discolorations in the tile cross-section were observed. These discolorations are due to various temperatures and unfortunately to the coolants used in the dissecting process, which makes the interpretation of the color stratas somewhat obscure. When water coolant was used, the RSI material showed water marks in a brownish color, while the TFE freon coolant discolored the grayish-white RSI to a pale green-gray color. Therefore, only a general discussion of these dissected test articles will be presented in this report. All specimens shown here were tested only once except the two LI-2200 test articles shown in figures 86 and 91 which were arc-jet tested twice. References used in arriving at the conclusions below were:

1) NASA research grant to the University of Texas at Dallas (NAG-1-256) in 1984, titled "Study of Outgassing and Decomposition of Space Shuttle Heat Protection Tiles, Fillers, and Adhesives" which reports outgassing and decomposition of organic matter contained in the RSI.

2) Kennedy Space Center (KSC) Laboratory Request No. MBC 039-86. Chemical analyses reports on the Shuttle Infrared Leeside Temperature Sensor (SILTS) program also indicated similar outgassing occurred on the tiles and silicous matter fogged the silicon windows.

The dissected tiles show stratas of black discoloration which indicate pyrolytic decomposition of organic matter. This decomposition starts at approximately 500 degrees F and as temperature increases the carbon fiber compositions in the structure of the tile are being vaporized. When this has occurred the black regions turn to a chalky white which indicate very high temperatures, in excess of 2500 degrees F.

This vaporized material deposits itself on the RCG coating of the surrounding tiles as silicon dioxide and carbon.

Furthermore, it should be noted that the fully bonded quartz tubes conducted more heat into the tile by way of the ceramic adhesive, as is evidenced by the chalky white discoloration of TPS material surrounding the quartz tube, in figure 85 below the RCG coating and half way down the quartz tube. Figures 86 (fully bonded test specimen) and 91 (partially bonded test article) indicate high temperatures around the quartz tube outside diameter by the chalky white discoloration. Also the melt down of the top inside diameter of both quartz tubes can be observed. Test articles shown in figures 87 (full bond) and 89 (partial bond were both exposed to a 2700 degrees F surface temperature. The white area surrounding the top of the tube shown in figure 87, suggests a higher temperature for the fully bonded tube as compared to the same area of the partially bonded tube depicted in figure 89. The white area in the test article illustrated in figure 88 (full bond) tested at 2800 degrees F suggests a much higher temperature area below the RCG coating than the test articles in figures 87 and 89. Figure 90 shows the partially bonded LI-900 test article after exposure to 2300 degrees F. It appears to have maintained most of its original color. At temperatures above 2700 degrees F the RCG coating becomes liquid and blisters develop over the tile surface.

STRUCTURAL TEST RESULTS

1) Quartz Tube Bending Test (straight tube)

A pull gauge was applied perpendicular to the quartz tube axis as depicted in figure 21 and the force to break the tube was determined.

After the bending tests were completed the specimens were dissected and the following results were observed:

A) no distortion of the tile RCG coating

B) no damage to the internal structure of the RSI

C) no debonding of the adhesives or fractures, the tubes remained solid in the tile

D) no damage to the remaining tube parts

E) the tubes broke cleanly at the flange

F) the break force range was between 3.9 to 5.3 pounds, the mean force was 4.6 pounds.

Photographs of the dissected test articles are shown in figures 92 through 94. Figure 92 depicts the three fully bonded test specimen, figure 93 the partially bonded test articles, and figure 94 illustrates a close-up of a partially bonded test article.

2) Quartz Tube Bending Test (90 degree bent tube)

A pull gauge was applied perpendicular to the quartz tube axis at the dimple at the end of the tube as depicted in figure 22 and the force to break the tube was determined.

After the bending tests were conducted the specimen were dissected and the following results were observed:

A) no distortion of the tile RCG coating

B) no damage to the internal structure of the tile

C) no debonding of the RTV 560 or fractures, the tubes remained solid in the tile

D) no damage to the remaining tube parts

E) the tubes broke cleanly near the flange

F) the break force was between 7.0 and 15.5 pounds, the mean force was 13.4 pounds with a standard deviation of 2.6.

A photograph of one test article is shown in figure 95.

3) Pressure Port Torque Test

The bondline between the quartz tubes and the RSI is relatively small, because the bond occurs at the outer flange only, as shown in figure 96. Face bonding on the flange is not utilized, because the adhesive would increase the gap requirement between the quartz tube tip and the RCG inner surface. Accounting for the bonding material thickness, it would be very difficult to maintain the tolerance of the specified gap of .002 plus or minus .001 as specified in LaRC drawing no. 158076.

A torque wrench with the appropriate sized socket was placed over the hex nut as illustrated in figure 23. The torque to break the quartz tube or loosen it from the RSI substrate was recorded.

The results were a mean torque of 5.6 inch-pounds to break a tube or debond it from the tile with a standard deviation of 1.2. Torques ranged from 4.0 to 7.0 inch-pounds. At 7.0 inch-pounds the quartz tubes broke while at lower torques the RTV bond line failed. The results showed that the bond is quite adequate to insure proper structural integrity of each of the penetration components.

4) Pressure Port Pull Test

A phenolic block which consisted of two halves was clamped over the ends of the protruding tubes and a pull gauge was attached to the block with a force indicator mounted to the gauge as shown in figure 24. The force was observed on the dial of the gauge and recorded.

The results were a mean pull-force of 16.3 pounds to break a tube from the tile, with a standard deviation of 2.9. The pull-forces ranged from 11.0 to 20.0 pounds. None of the quartz tubes failed. Half of the twelve test specimen broke loose by shearing through the RTV at the flange circumference and the other half failed in the RSI fiber material. The results indicate that the bond between tube and TPS was quite satisfactory to insure proper structural integrity of each of the individual penetration components.

5) Ninety Degree Bent Tube Cross-sectional Area Change

The dissected tubes were elliptical in cross-section as depicted in figure 21. The elliptical cross-section was measured along the major and minor axes and the area calculated. The cross-sectional area change ranged between 2.10% and 18.63% with a mean change of 11.64% and with a standard deviation of 5.11.

These results indicate that no significant changes in the pressure system response will occur.

THERMAL ANALYSES

PRESSURE PORT THERMAL ANALYSIS

A thermal model of the stagnation region quartz tube and tile was developed using the Systems Improved Numerical Differencing Analyzer (SINDA-85). Baseline V stagnation heating rates were used as inputs to the model. The tube-in-tile model was based on the schematic configuration shown in figure 97. Both normal and failure cases were analyzed. In the failure case, a pre-aeropass fracture of the quartz tube would allow hot boundary layer gases to flow through the tube. The peak quartz temperature histories for both normal and failure cases is shown in figure 98. The highest temperature experienced by the quartz tube was approximately 2370 degrees F for the failure case. Since the quartz tubing has a 2876 degree F softening temperature, and a 3477 degree

F melting point, erosion of the quartz tubing in the failure case should not occur. The other area of concern was the interface temperature between the quartz tubing and the fluoroelastomeric (Viton) tubing during normal operation. The specified temperature limits for fluoroelastomers are -10 degrees F to 400 degrees F in continuous use, with a 600 degree upper limit in intermittent use. Results from the normal case analysis predict a peak interface temperature between the fluoroelastomer and the quartz tubing of approximately 510 degree F. Thus, no problem is expected.

ARC-JET TESTS

Several of the arc jet tunnel tests were configured to simulate a failure of the stagnation region pressure port during aeropass. In order to do this, the Viton tubing was removed from the quartz tube. This allowed mass flow through the quartz tube during the test run. A crude flat plate calorimeter was situated behind the open quartz tube in the stream of the impinging flow. Two thermocouples were installed on the back side of the plate to allow an assessment of the heating uniformity to be made. The test setup is shown in figures 18 and 19. Typical thermocouple responses for test run 914 are shown in figure 99. As seen in the figure, temperatures across the plate were close to being uniform. Neglecting radiative and conductive losses from the plate, an impingement heating flux was calculated for each failure mode test. The resulting heating flux curve for run 914 is shown in figure 100. The peak impingement flux was 0.75 Btu/ft^2-sec. This low rate suggests that even a stagnation region pressure port failure will have little effect upon the heating environment inside of the aerobrake.

ANALYTICAL RESULTS AND TEST DATA

The heating profile obtained in arc jet testing closely resembles a step function. The test article is inserted into the arc jet at zero seconds, and remains there for approximately 150 seconds. At the end of that time the model is withdrawn from the arc. Since the predicted Baseline V heating profile is not a step function, comparison of the arc jet heating with Baseline V heating was necessary to validate the testing. The heating was compared in two ways. First, the peak heating rates were compared. Secondly, the integrated, total heating values of the step function heating and the Baseline V heating profile were calculated and compared. Heating rates for the arc jet tests were calculated using surface temperature data, and radiation equilibrium methods. These heating rates are summarized in figure 101. In general, these rates are comparable to the peak heating rate of 42 Btu/ft^2-sec predicted in the Baseline V data. A graphical integration of the Baseline V heating profile was performed in order to compare the total applied heating between Baseline V and the arc jet tests. The total Baseline V heating for the period of the aeropass (0 to 450 seconds) is approximately 6592 Btu/ft^2. This total heat load is numerically equivalent to a step function heating rate of approximately 44 Btu/ft^2-sec applied for 150 seconds. This heating rate is typical of the arc jet test heating rates, which ranged from 37-54 Btu/ft^2-sec. The step function heating rate profile is plotted against the Baseline V heating rate in figure 102. Results from the PD/ADS arc jet testing were used to validate the mathematical model of the PD/ADS pressure port assembly. The calculated step function heating rates from the arc jet testing were applied to the surface nodes of the mathematical model for 150 seconds. Temperature predictions from the closest corresponding nodes in the math model were then compared against the thermocouple temperatures taken at several points through the test article during the arc jet testing. A comparison plot for the SIP/LI-2200 interface temperature is shown in figure 103. As shown in the figure, the two responses are quite similar. A falling temperature for the arc jet after 400 seconds is attributed to the presence of the water cooled test fixture which holds the test article. This fixture was not present in the mathematical model.

CONCLUSIONS

The PD/ADS pressure measurement system underwent extensive design development and test activities to prove the soundness of this design approach and the compatibility of this system with the RCG coated high temperature insulation tiles. This design and test program may also be of interest to some of the other experiments on the AFE spacecraft.

VIBRO-ACOUSTIC

The test objectives of this program were met. The vibro-acoustical performance data were obtained and all design configurations survived the prescribed tests successfully. The test articles satisfactorily passed not only the design requirement vibration level of 7.5 Grms but also the overtests of 10 Grms and 24 Grms. No damages, separation of parts, or dimensional deformities were observed in any of the components of the pressure port penetration test assemblies. Thus the PD/ADS pressure port penetration system design was concluded to be acceptable.

AERO-THERMAL

All test objectives were achieved and are summarized in tables 5 and 6 at the 150 second data point just before test article extraction. Table 7 presents the peak temperatures at the various test points. The thermal performance data were acquired for both candidate AFE pressure port designs, i.e. the full bond and the partial bond, to determine the compatibility of these designs with the RCG coated LI-900, FRCI-12, and LI-2200 high temperature insulation tiles. This pressure port system was found to have acceptable thermal performance for surface temperatures of 2300 degrees F, 2800 degrees F, and 2900 degrees F for tile densities of 9 pounds/cubic foot (PCF), 12 PCF, and 22 PCF respectively.

Although melting of the RCG coating occurred around the probe tips of some test articles the dimensional stability of the pressure probe orifices for both designs proved to be quite adequate to prevent catastrophic overheating at the pressure port tips. The probe test articles had negligible changes in their surface contours with variations of less than 0.010 inches.

Failure modes were also evaluated for both pressure port designs with a loose pressure line simulating a broken quartz tube (LI-2200 insulation tile) with a partially bonded pressure port with a chipped out RCG coating around the probe tip (FRCI-12 insulation tile). The failure test temperatures and pressure results are summarized in tables 8 and 9. These tests demonstrated that the loose pressure line failures are benign for the LI-2200 tile surface temperatures up to 2900 degrees F at 59 psf and the chipped out RCG coating failure is also harmless for the FRCI-12 tile surface temperature up to 2700 degrees F at 49 psf. The overall aero-thermal test performances were entirely satisfactory and this test program proved that these designs are thermally and structurally acceptable as candidate PD/ADS designs for the AFE program.

STRUCTURAL

The structural tests discussed in the previous sections in this report demonstrated that the designs presented here are sound and of adequate structural integrity and do not render any hazards to any of the components.

PD/ADS VIBRATION TEST MATRIX

TYPE	AXIS	FREQUENCY	LEVEL	DURATION
SINUSOIDAL SWEEP	Z	10-200 Hz	.25-.50 Grms	4 MIN, 19 SEC
RANDOM	Z	20-2000 Hz	7.5 Grms	60 SEC
RANDOM	X	20-2000 Hz	7.5 Grms	60 SEC
RANDOM	Y	20-2000 Hz	7.5 Grms	60SEC
RANDOM	Y	20-2000 Hz	10.1 Grms	20 SEC
RANDOM	Z	20-2000 Hz	10.1 Grms	20 SEC
RANDOM	Z	20-2000 Hz	24.2 Grms	20 SEC
RANDOM	X	20-2000 Hz	24.2 Grms	20 SEC

TABLE 1

TABLE 2
SPECTRUM DATA
Grms = 7.5

FREQUENCY HZ	LEVEL G^2/Hz	SLOPE db/OCT
20	P1 = 0.02	
20 to F1 = 160		a1 = 2
F1 = 160	P2 = 0.08	
F2 = 250	P3 = 0.08	
F2 = 250 to 2K		a2 = -3
2K	P4 = 0.01	

TABLE 3
TEST MATRIX

RUN NUMBER	TEST ARTICLE	TARGET TEMP. DEGREE F	CAL. MODEL TEMP. DEG. F	PITOT PRESS. PSF	QUARTZ/VITON PEAK TEMP. DEGREE F
913	1-L9FB-157	2300	2290	39.2	233
906	6-L9-162	2300	2290	39.3	158
907	3-F12FB-159	2700	2697	48.7	266
908	5-F12-161	2700	2697	50.1	297
909	4-F12FB-160	2800	2803	51.8	351
910	8-F12-164	2800	2803	50.9	250
912	2-L22FB-158	2900	2902	59.5	343
911	7-L22-163	2900	2902	57.9	284
914	2-L22FB-158	2900	N/A	59.5	N/A
916	7-L22-163	2900	N/A	60.3	N/A
915	8-F12-164	2700	N/A	49.9	445

1) TEST TIME = 150 SECONDS FOR ALL RUNS
2) FB = FULLY BONDED; L9 = LI-900; F12 = FRCI-12; L22 = LI-2200
3) RUNS 914 AND 916 WERE LOOSE TUBING FAILURE MODES
4) RUN 915 WAS CRACKED RCG COATING FAILURE MODE

TABLE 4
PRESSURE PORT TEST ARTICLE THICKNESS MEASUREMENTS

RUN NUMBER	TEST ARTICLE	TARGET TEMP DEGREE F	PRE-TEST THICKNESS IN.	POST-TEST THICKNESS IN.
913	1-L9FB-157	2300	N/A	N/A
906	6-L9-162	2300	1.117	1.106
907	3-F12FB-159	2700	1.106	1.102
908	5-F12-161	2700	1.106	1.099
909	4-F12FB-160	2800	1.086	1.070
910	8-F12-164	2800	1.124	1.111
912	2-L22FB-158	2900	1.101	N/A
911	7-L22-163	2900	1.115	1.112
914	2-L22FB-158	2900	N/A	1.094
916	7-L22-163	2900	1.115	1.093
915	8-F12-164	2700	1.124	1.109

PD/ADS ARC-JET TEST RESULTS

TILE MAT'L BOND TYPE	PITOT PSF	SURF TEMP DEGREE F	T/C2 TEMP DEGREE F	T/C3 TEMP TEMP	T/C8 TEMP DEGREE F
FRCI-12 CAL	42.66	2704	0.00	0.00	0.00
FRCI-12 F/B	48.72	2697	152.22	93.40	171.62
FRCI-12	50.29	2702	153.41	105.23	162.95
FRCI-12 CAL	45.45	2803	0.00	0.00	0.00
FRCI-12 F/B	51.76	2795	154.61	94.55	229.78
FRCI-12	50.86	2800	150.15	90.41	149.23
FRCI-12 CAL	52.06	2902	0.00	0.00	0.00
LI-2200	57.90	2922	120.79	91.47	203.24
LI-2200 F/B	59.56	2923	108.60	88.33	250.76

ALL TEMPERATURES WERE RECORDED 150 SECONDS AFTER TEST ARTICLE INSERTION INTO THE ARC-JET STREAM.

TABLE 5

PD/ADS TILE PENETRATION ARC-JET SUMMARY

TILE MAT'L BOND TYPE	MASS FLOW LB/SEC	CURRENT AMPS	VOLTAGE VOLTS	ENTHALPY BTU/LB	TRANSDUCER PSF	PITOT PSF	SURF TEMP F	VANZETTI @ .90 TEMP F	TILE/SIP TEMP F T/C2	SKIN TEMP F T/C3	TUBE/VITON TEMP F T/C8
FRCI-12 CAL	.250	531	3141	4495	------	30.24	2290	2228.37	-----	-----	------
LI-900 F/B	.252	531	3155	4445	3.01	39.25	2276	2197.27	79.14	82.15	127.35
LI-900	.251	530	3156	4502	46.26	46.26	2293	2228.49	145.87	89.67	118.67
FRCI-12 CAL	.250	1151	2749	7559	------	42.66	2704	2700.80	-----	-----	------
FRCI-12 F/B	.252	1235	2728	7765	55.35	48.72	2697	2646.13	152.22	93.40	171.62
FRCI-12	.248	1235	2718	7924	57.06	50.29	2702	2702.14	153.41	105.23	162.95
FRCI-12 CAL	.250	1415	2648	8517	-----	45.45	2803	2774.90	-----	-----	------
FRCI-12 F/B	.250	1417	2652	8513	58.96	51.76	2795	2729.96	154.61	94.55	229.78
FRCI-12	.250	1415	2639	8443	57.57	50.86	2800	2729.88	150.15	90.41	149.23
FRCI-12 CAL*	.250	1446	2644	8574	-----	52.05	2902	2727.56	-----	-----	------
LI-2200*	.251	1452	2623	8555	66.97	57.90	2922	2790.33	120.79	91.47	203.24
LI-2200 F/B*	.250	1451	2625	8649	69.45	59.56	2923	2830.42	108.60	88.33	250.76

1. ALL DATA WAS TAKEN AT 150 SECONDS AFTER TEST ARTICLE INSERTION.
2. ALL DATA WAS TAKEN AT Z=10" EXCEPT NOTED BY*
   * DATA TAKEN AT Z=8".
3. ARC-JET CHAMBER PRESSURE WAS 250 MICRON.

TABLE 6

PD/ADS ARC-JET TEST PEAK TEMPERATURES

TILE MAT'L BOND TYPE	TARGET TEMP DEGREE F	T/C2 TEMP DEGREE F	T/C3 TEMP DEGREE F	T/C8 TEMP DEGREE F
FRCI-12	2700	413.69	111.46	296.61
FRCI-12 F/B	2800	405.13	109.92	350.67
FRCI-12	2800	401.84	110.57	249.57
LI-2200	2900	388.28	108.35	283.88
LI-2200 F/B	2900	387.66	110.13	342.57

TABLE 7

PD/ADS ARC-JET FAILURE TEST RESULTS

TILE MAT'L BOND TYPE	PITOT PSF	SURF TEMP	T/C2 TEMP	T/C3 TEMP	T/C9 TEMP	T/C10 TEMP
FRCI-12 T/P	49.81	2697	0.00	0.00	0.00	0.00
FRCI-12	49.83	2703	123.99	83.54	0.00	0.00
FRCI-12 T/P	59.66	2902	0.00	0.00	0.00	0.00
LI-2200 F/B	59.65	2907	96.42	110.33	220.20	222.83
LI-2200	60.31	2911	106.57	112.91	230.61	232.31

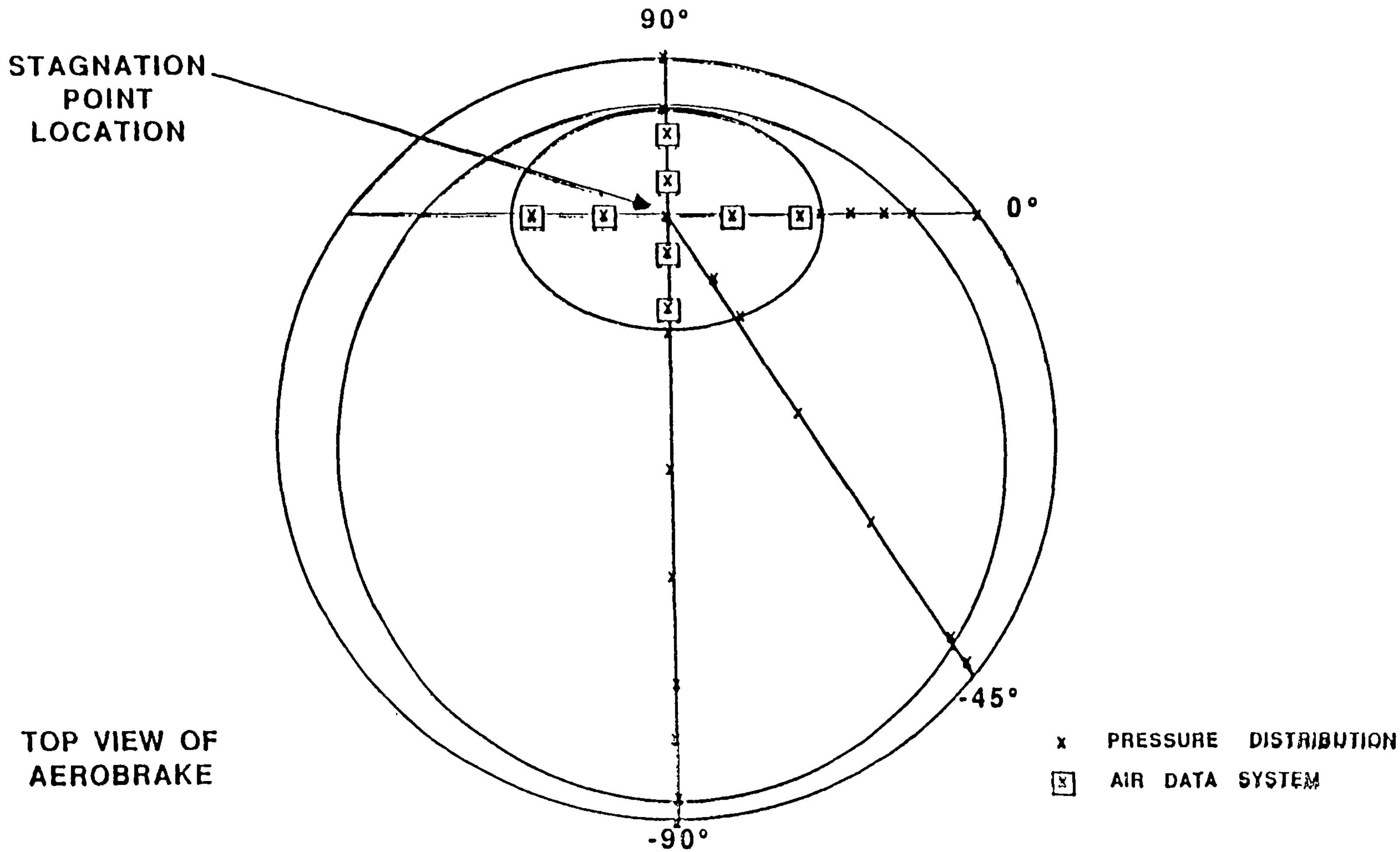
TABLE 8

PD/ADS TILE PENETRATION FAILURE TEST SUMMARY

TILE MATL BOND TYPE	MASS FLOW LB/SEC	CURRENT AMPS	VOLTAGE VOLTS	ENTHALPY BTU/LB	PITOT PRESS PSF	SURFACE TEMP F	VANZETTI @ .90E TEMP F	TILE/SIP TEMP F T/C2	SKIN TEMP F T/C3	IMPINGEMENT PLATE T/C9	IMPINGEMENT PLATE T/C10
FRCI-12 T/P	.250	1235	2718	7924	49.81	2697	2700.80	-------	-----	------	------
FRCI-12	.252	1236	2735	8022	49.83	2703	2655.00	123.89	83.54	------	------
LI-2200 T/P	.250	1451	2623	8649	59.66	2902	2727.56	-------	------	------	------
LI-2200 F/B	.250	1453	2638	8920	59.65	2907	2812.56	96.42	110.33	220.20	222.83
LI-2200	.253	1453	2663	8837	60.31	2911	2827.89	105.57	112.91	230.61	232.31

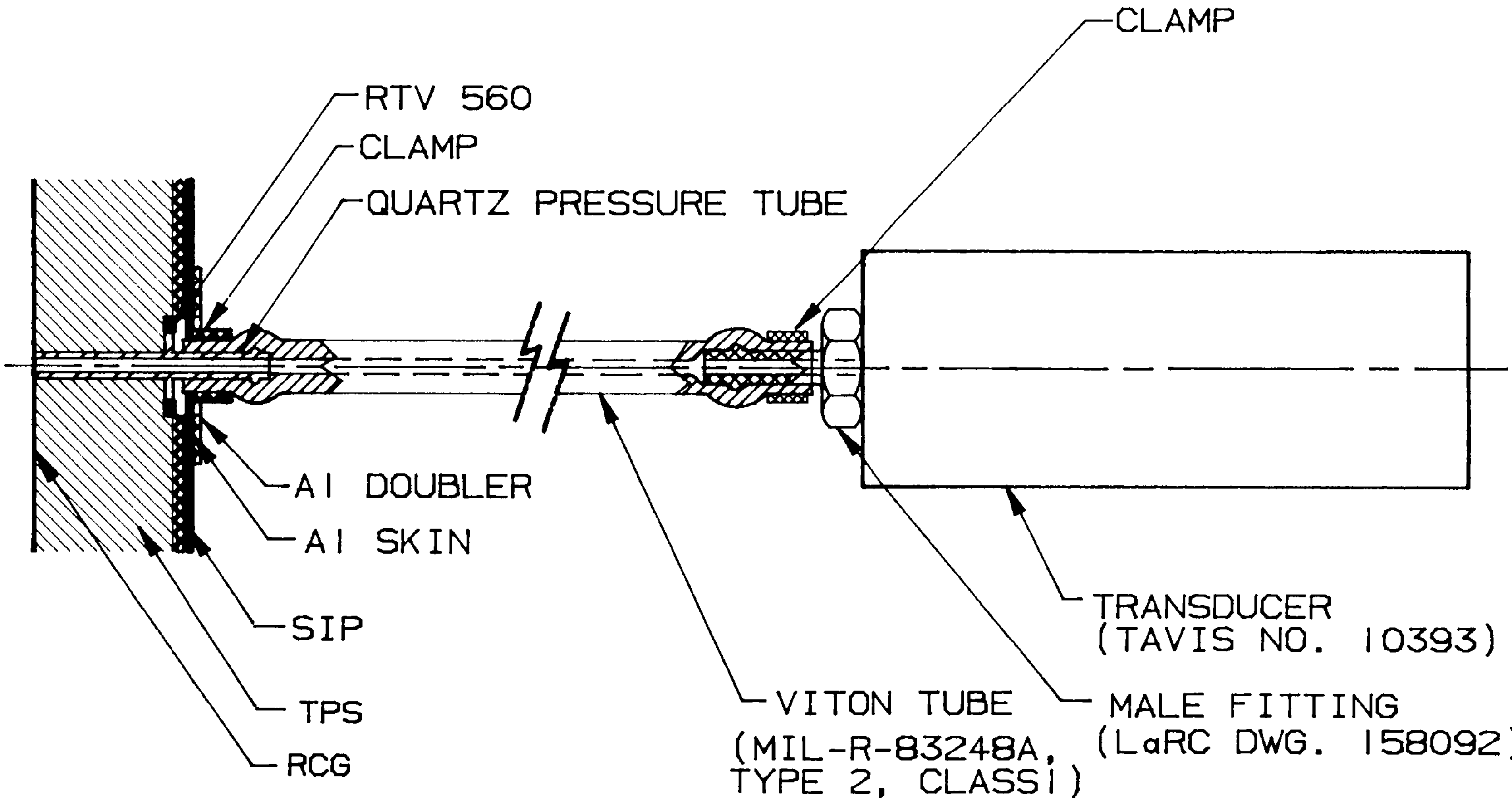
1. ALL DATA WERE TAKEN AT 150 SECONDS AFTER TEST ARTICLE INSERTION.
2. ALL TEST ARTICLES WERE TESTED ONCE BEFORE.
3. THE FRCI-12 TILE TESTED AT 2800 DEGREES F BEFORE; THE RCG COATING HAD FRACTURES BEFORE THIS TEST.
4. THE ARC-JET CHAMBER PRESSURE WAS 250 MICRON.
5. THE TWO LI-2200 TEST ARTICLES HAD THE VITON TUBES REMOVED AND IMPINGEMENT PLATES 1 INCH BELOW THE VYCOR TUBE WERE INSTALLED. THESE PLATES WERE ALSO USED AS SLUG CALORIMETERS.
6. THE FRCI-12 TO ARC DISTANCE WAS Z=10" AND THE LI-2200 TO ARC DISTANCE WAS Z=8".

TABLE 9



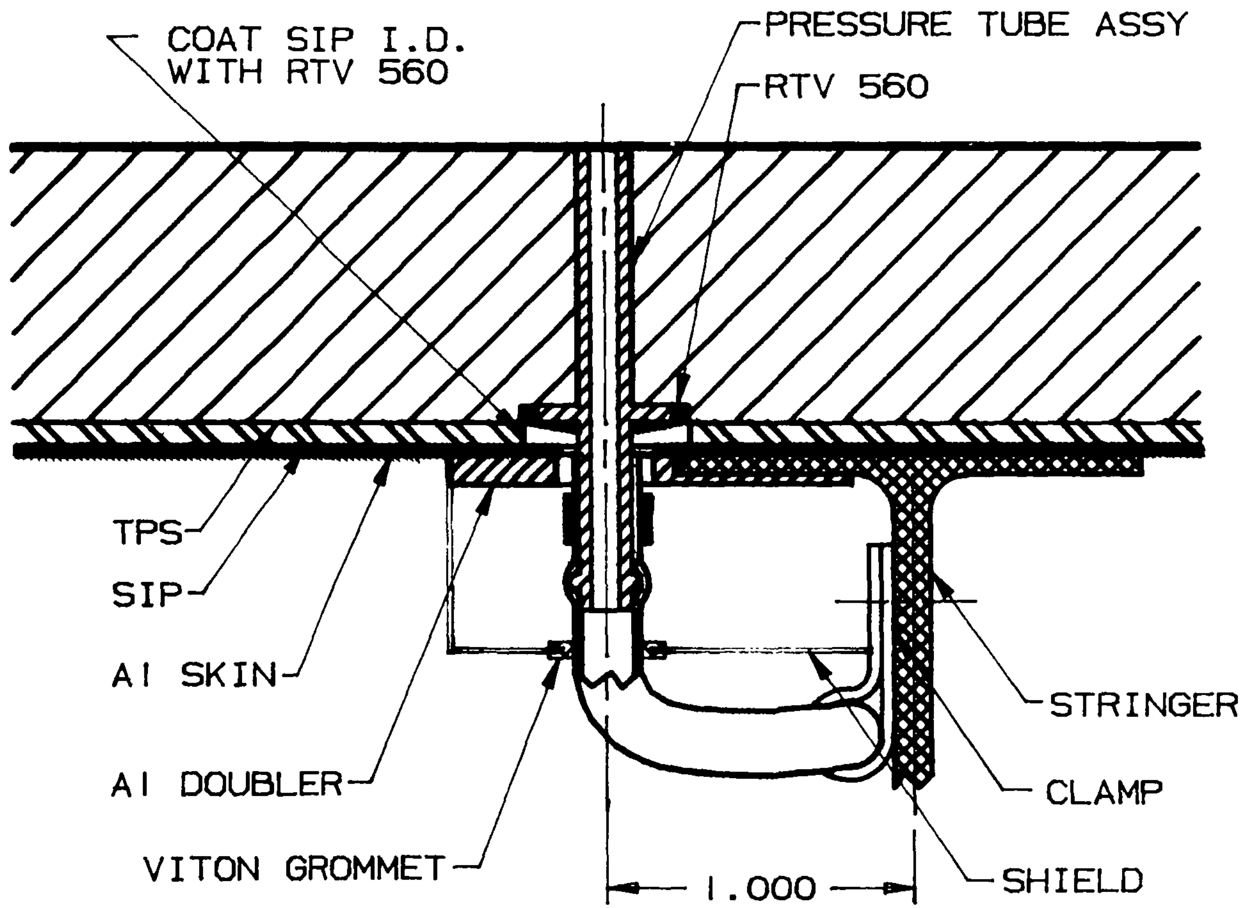
PRESSURE DISTRIBUTION / AIR DATA SYSTEM
EXPERIMENT LAYOUT

Figure 1



PRESSURE MEASUREMENT SYSTEM

FIGURE 2



STRINGER-PRESSURE PORT INTERFACE

FIGURE 3

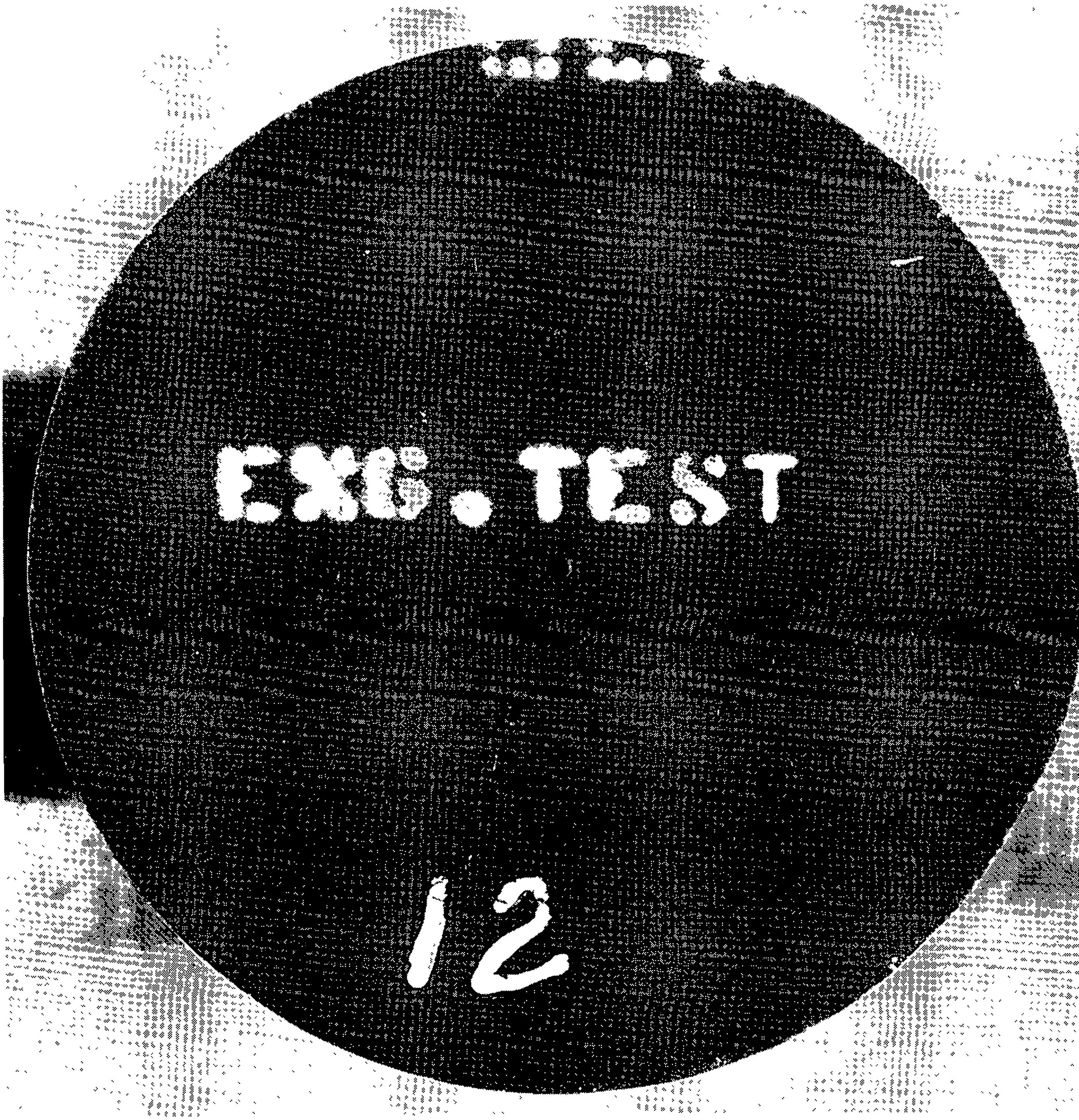


Figure 4 Pretest 8-F12-164, 2800 degrees F partially bonded, front view

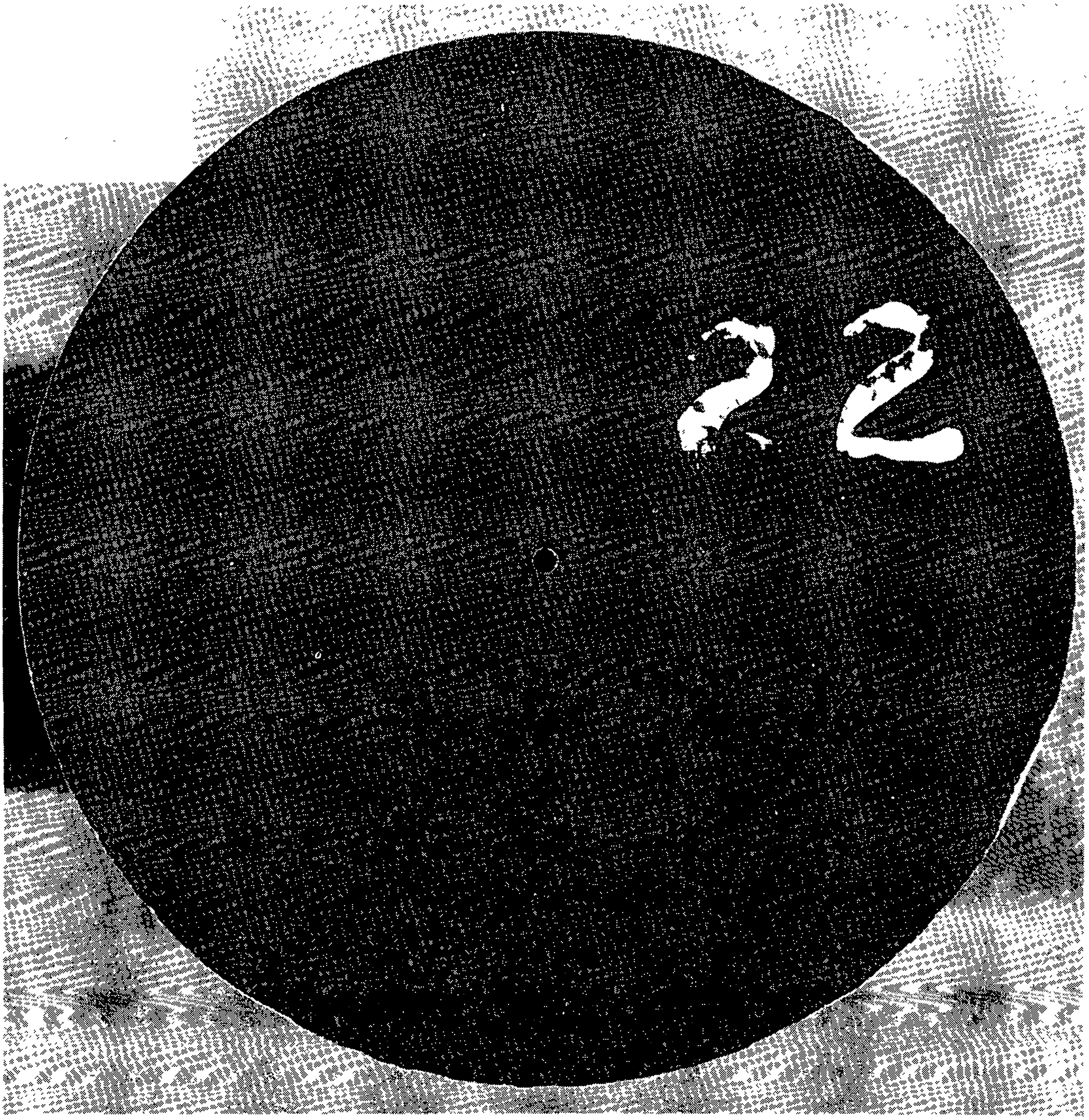


Figure 5 Pretest 7-L22-163, 2900 degrees F partially bonded, front view

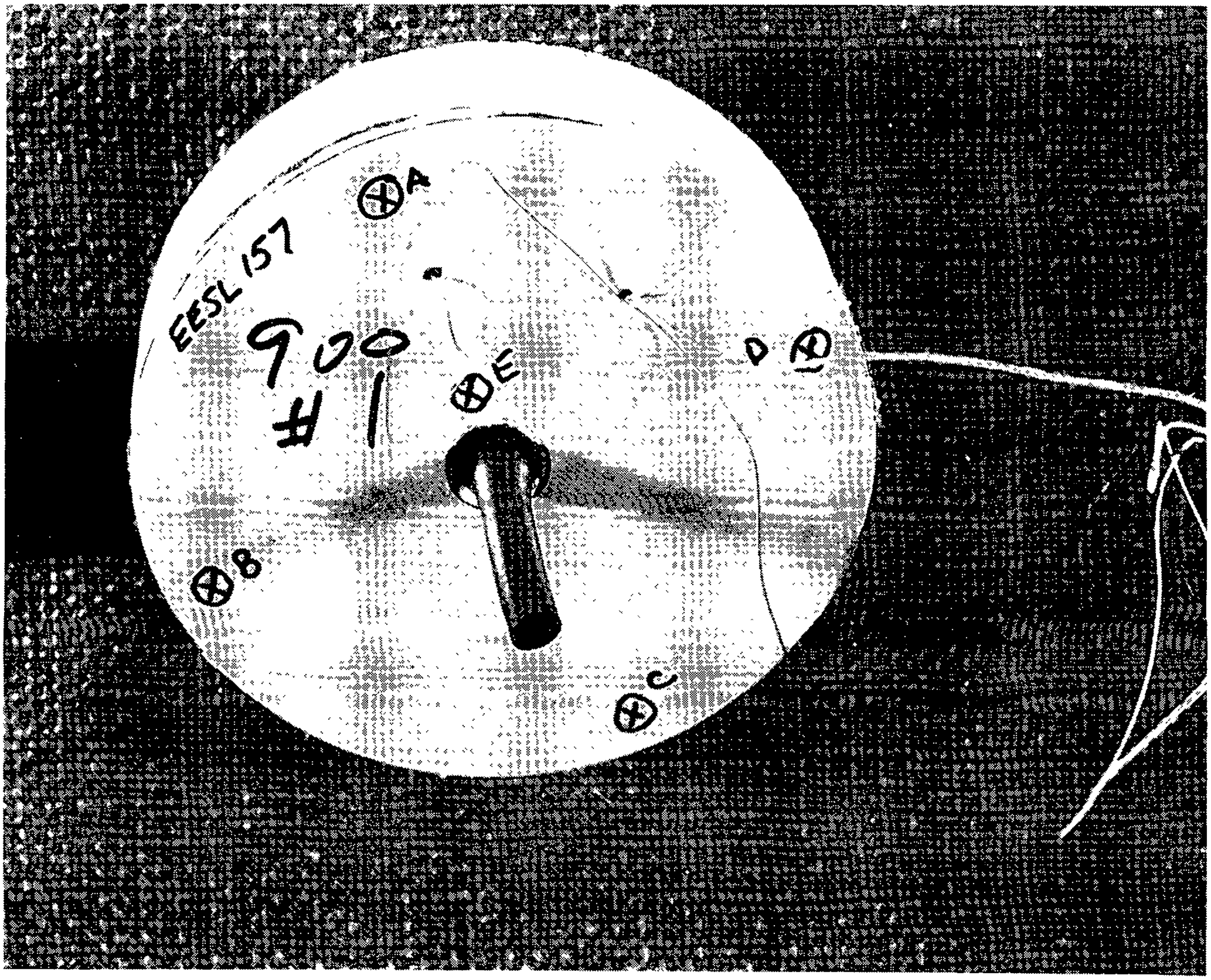
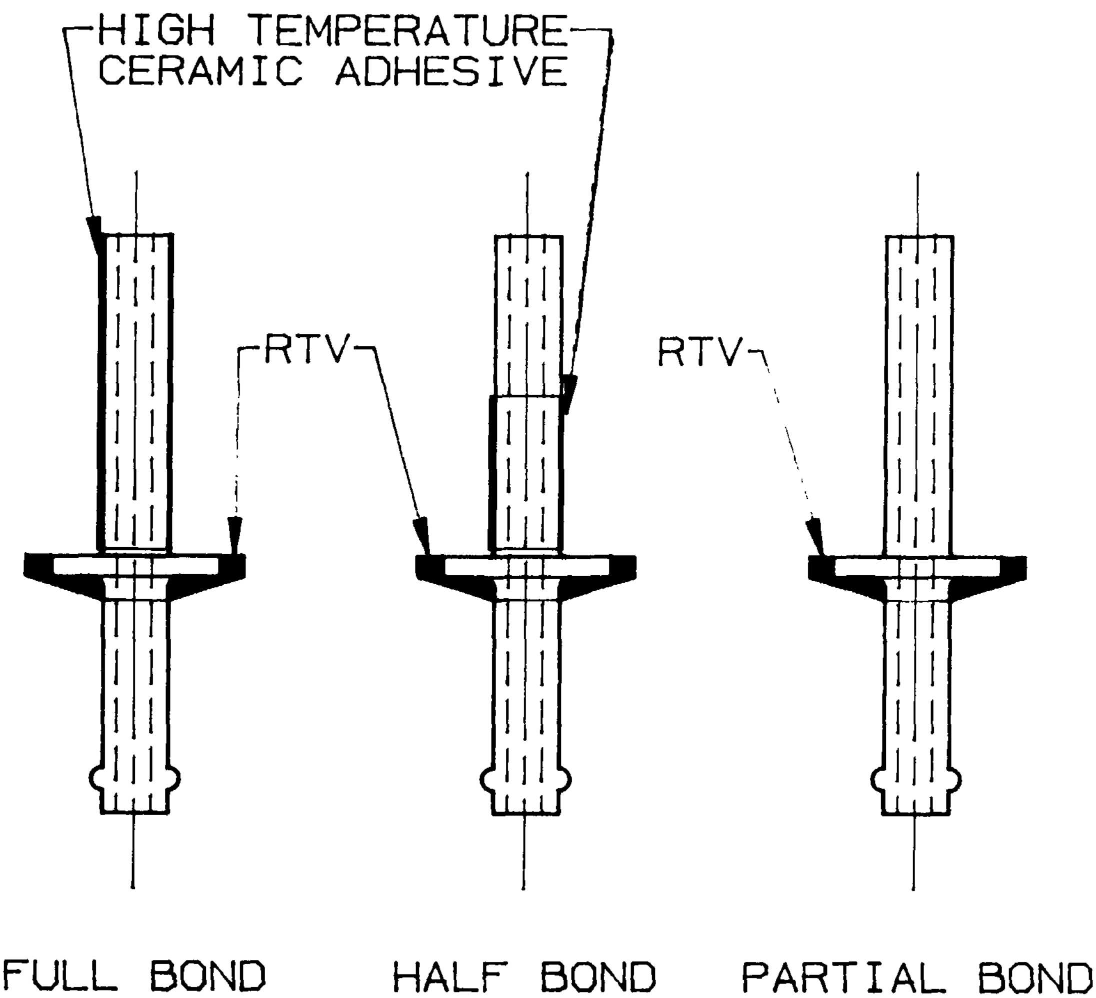
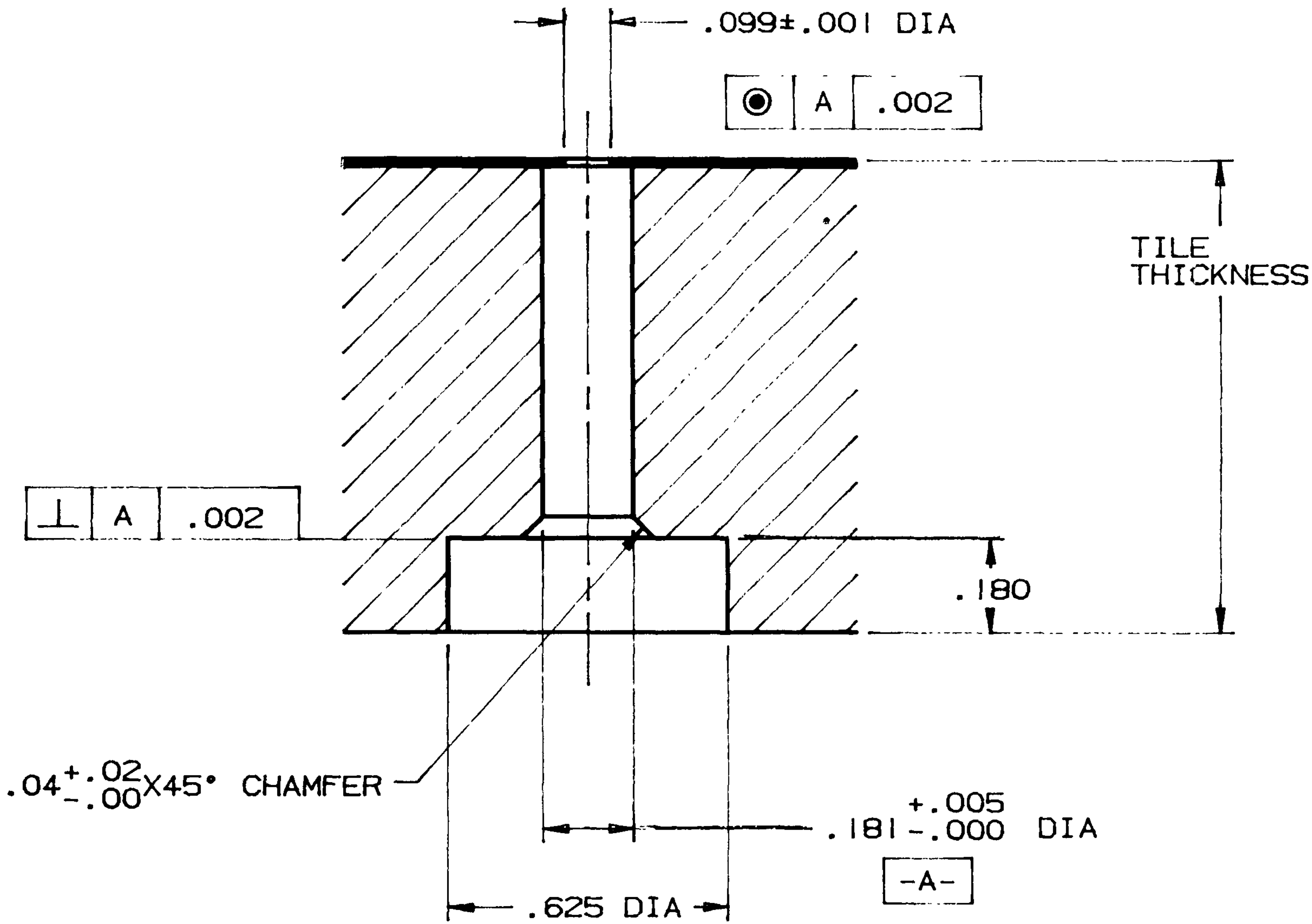


Figure 6 Pretest 1-L9FB-157, 2300 degrees F fully bonded, rear view



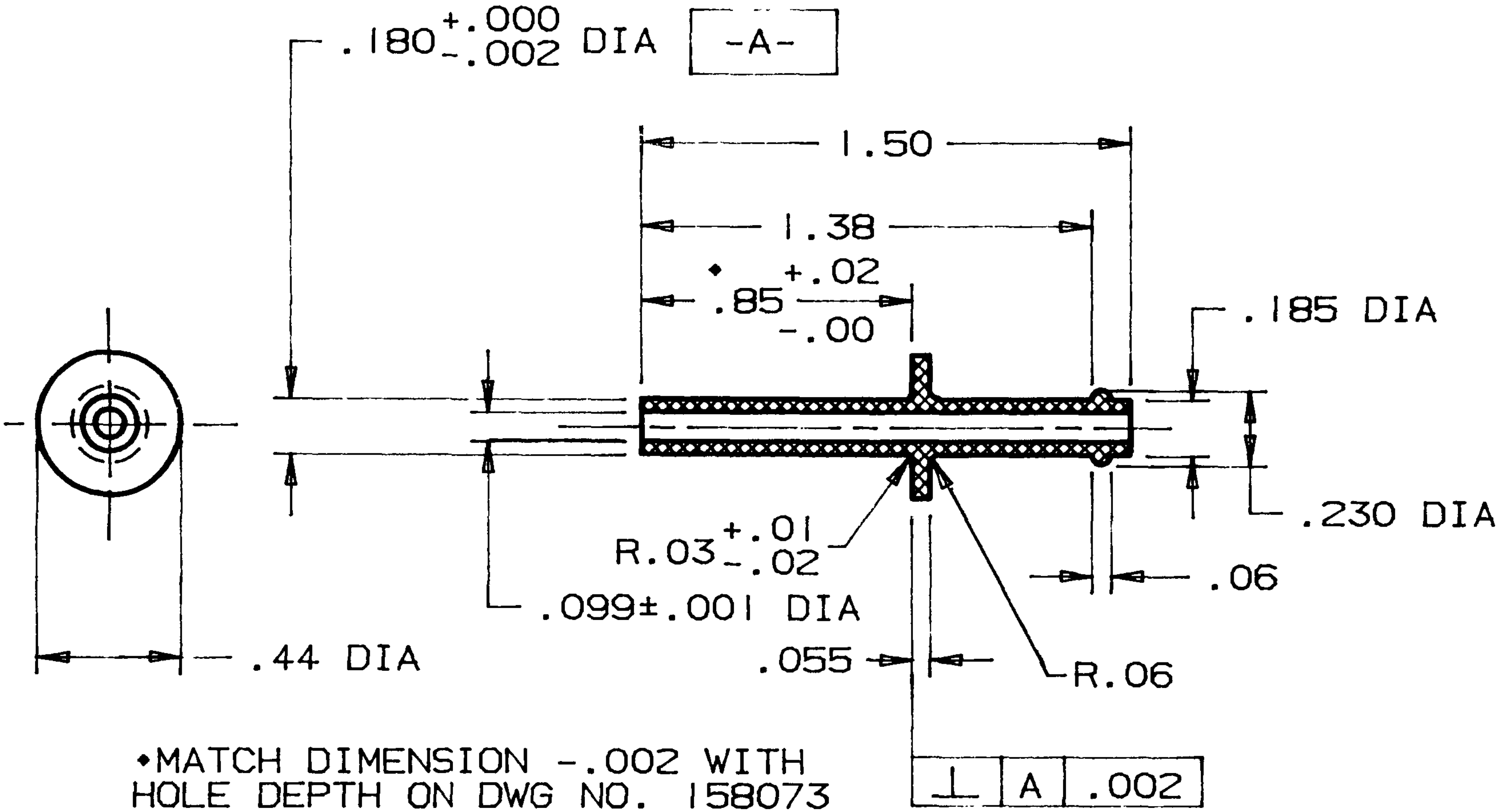
3 BONDING METHODS

FIGURE 7



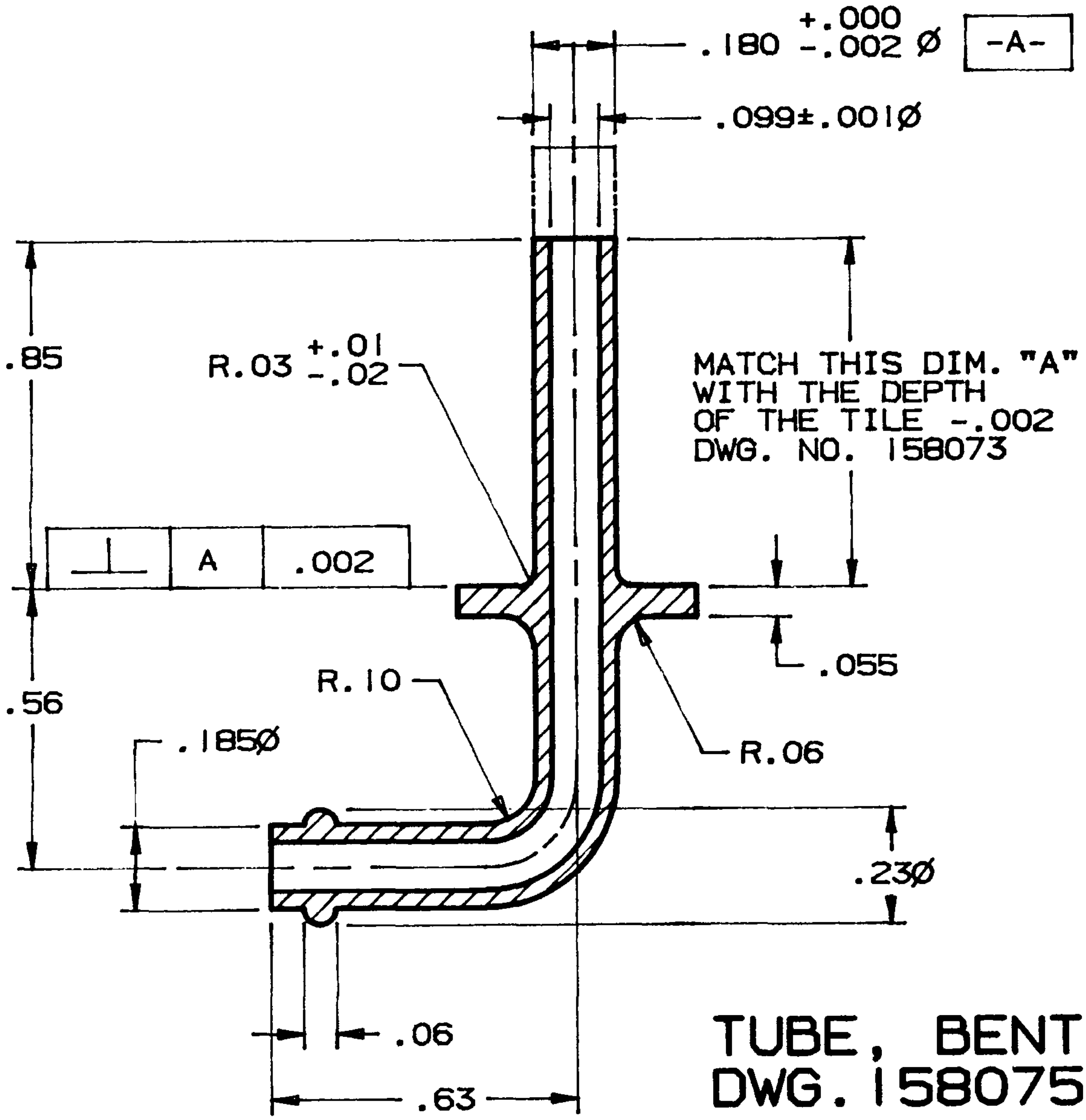
TYP. TILE CORING PER DWG NO. 158073

FIGURE 8



TUBE, STRAIGHT DWG NO. 158074

FIGURE 9



.180 +.000 -.002 Ø
-A-
.099±.001Ø
.85
R.03 +.01 -.02
MATCH THIS DIM. "A"
WITH THE DEPTH
OF THE TILE -.002
DWG. NO. 158073
A
.002
.055
.56
R.10
.185Ø
R.06
.23Ø
.06
.63
TUBE, BENT
DWG. 158075

FIGURE 10

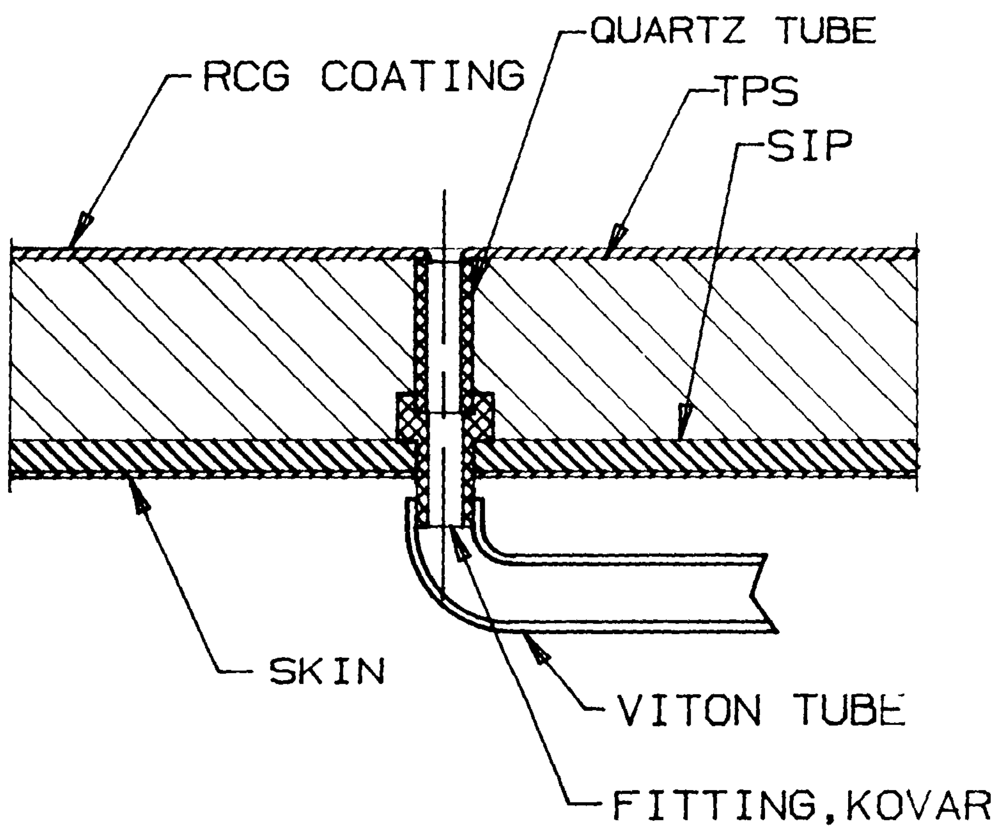


Figure 11 **Penetration Concept 1**

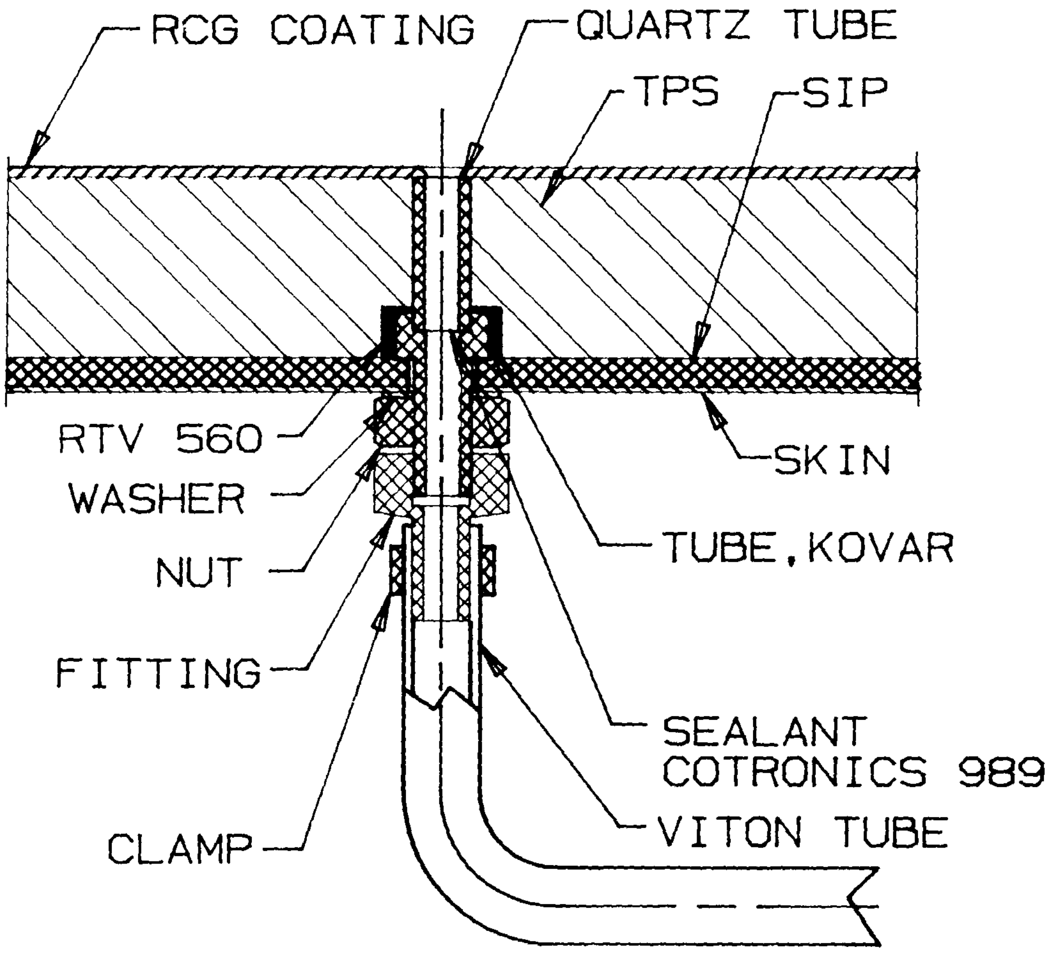


Figure 12 Penetration Concept 2

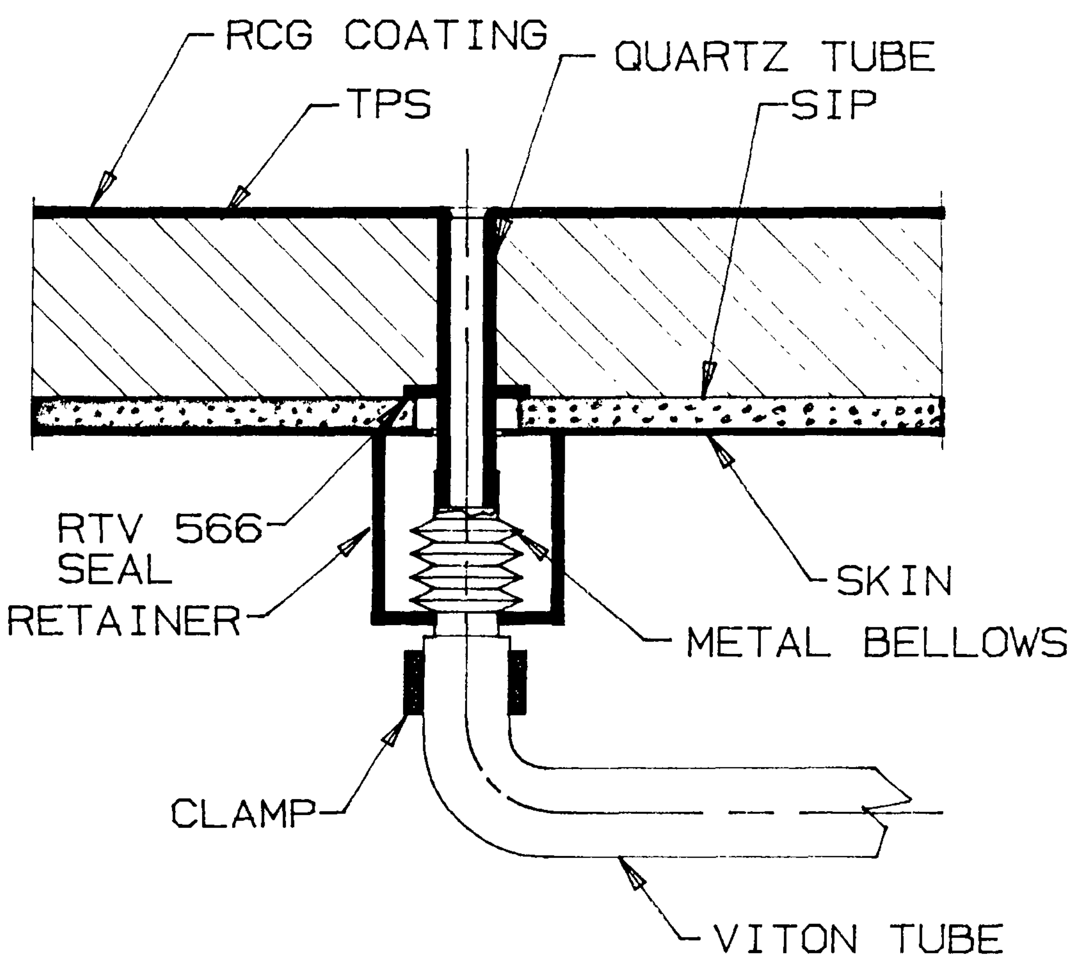
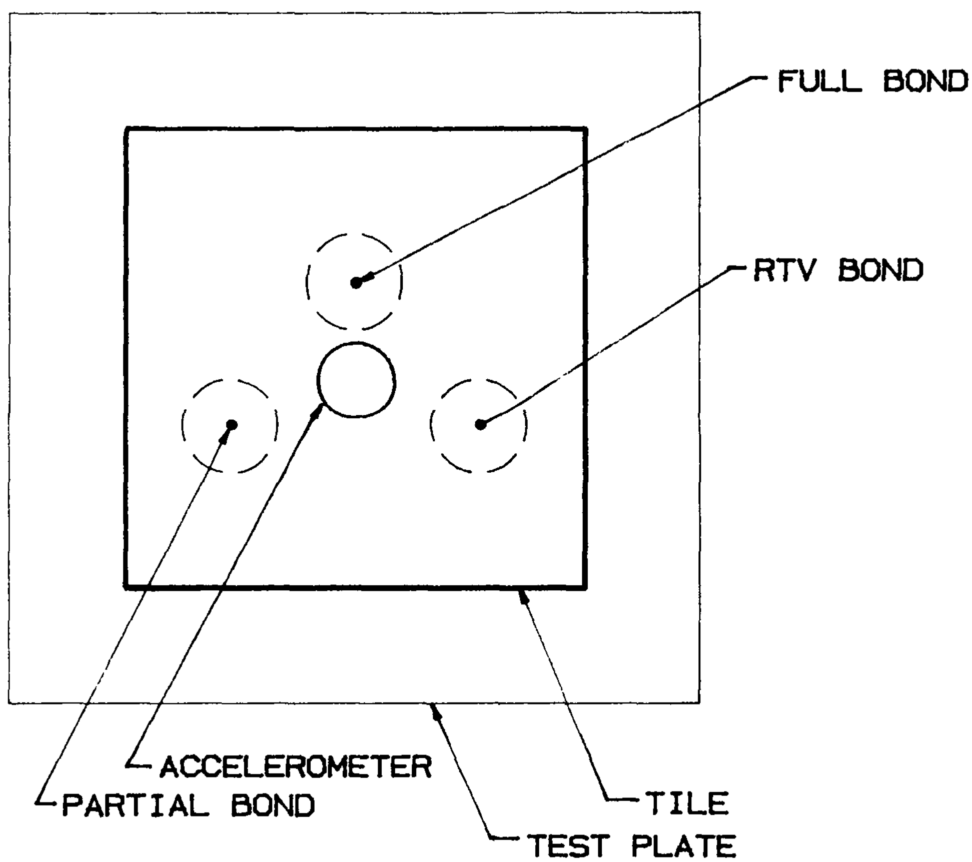
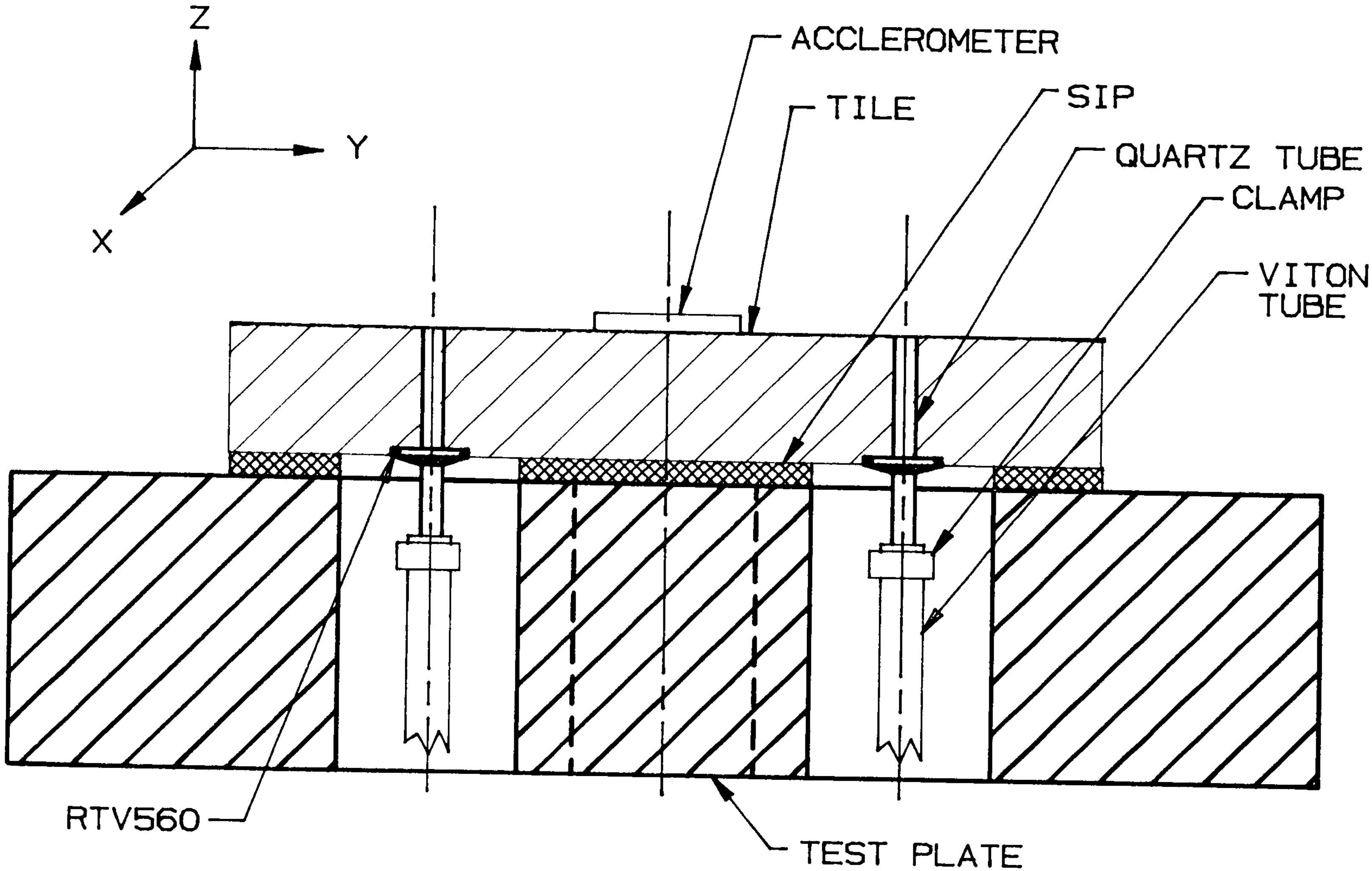


Figure 13 Penetration Concept 3



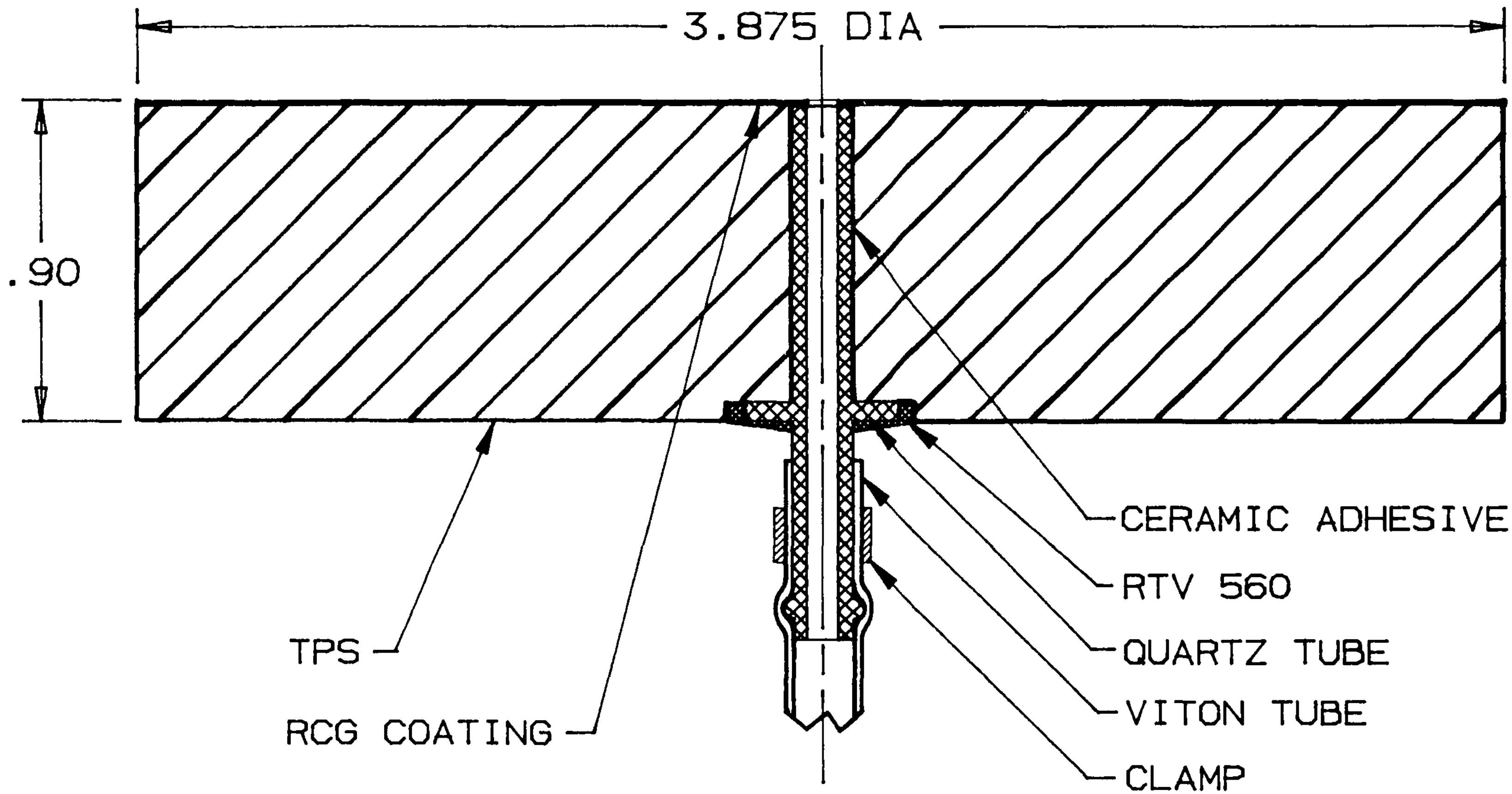
PD/ADS VIBRATION TEST ARTICLE
TOP VIEW

FIGURE 14



PD/ADS VIBRATION TEST ARTICLE

FIGURE 15



PD/ADS ARC-JET TEST ARTICLE

FIGURE 16

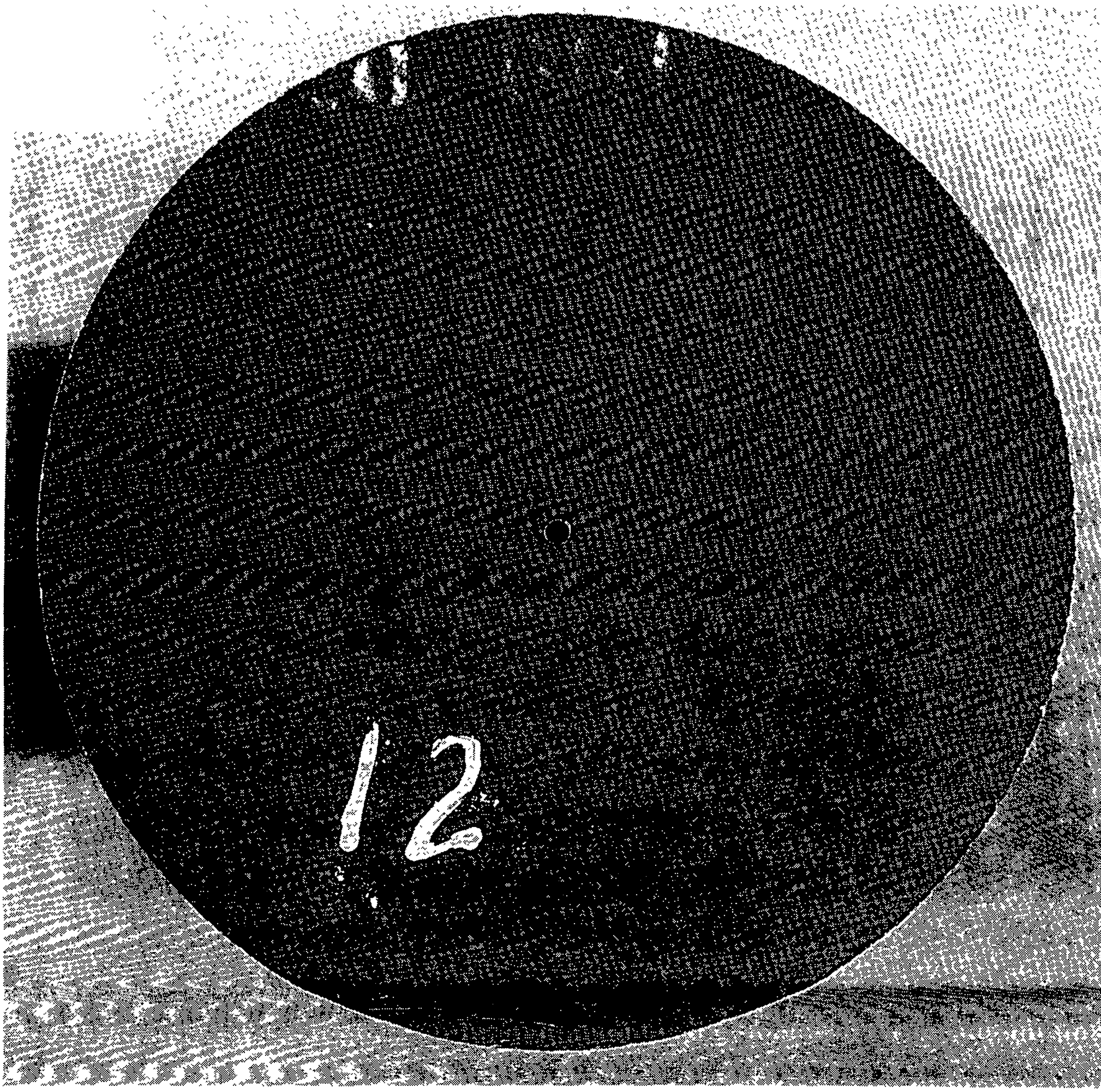
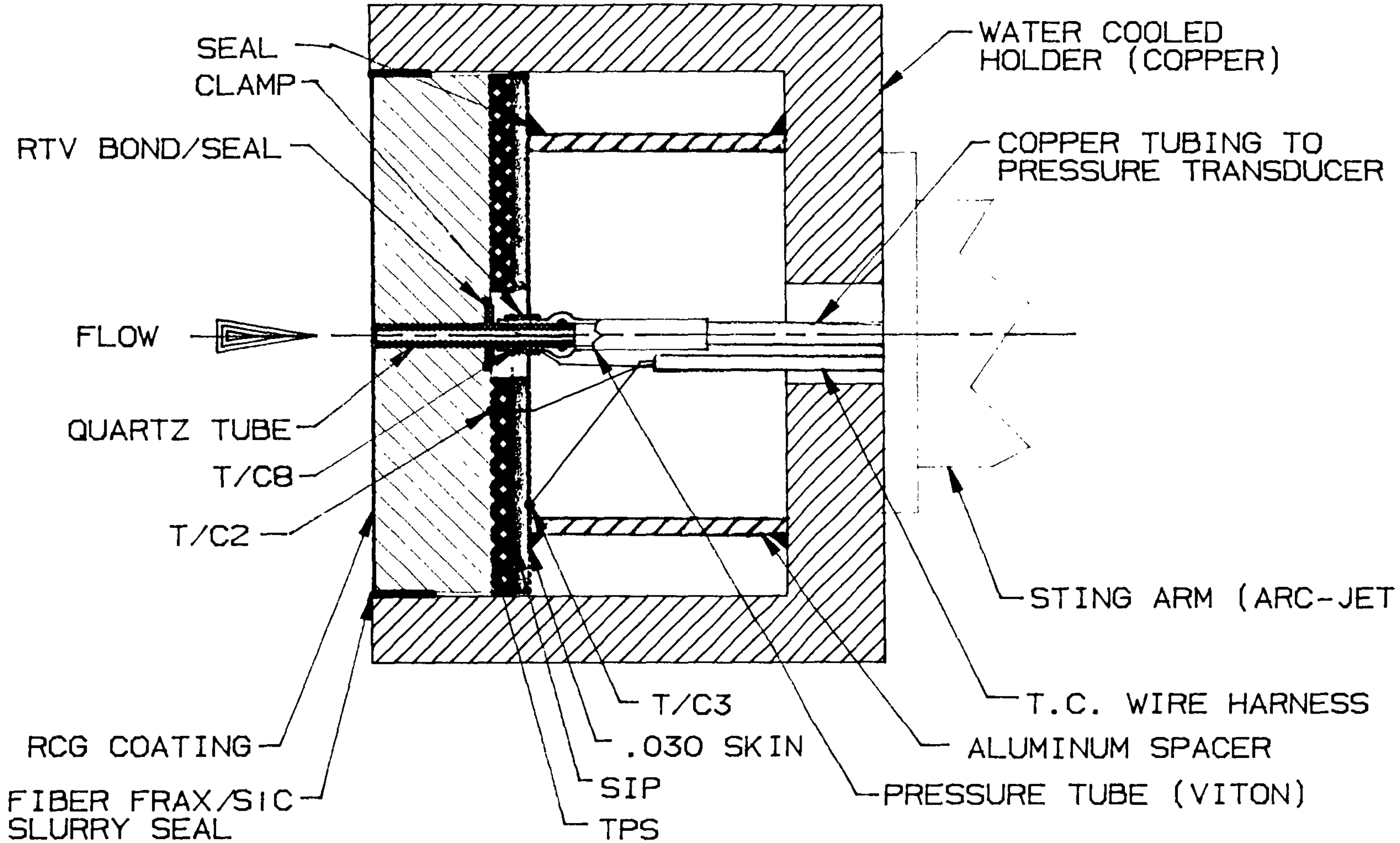


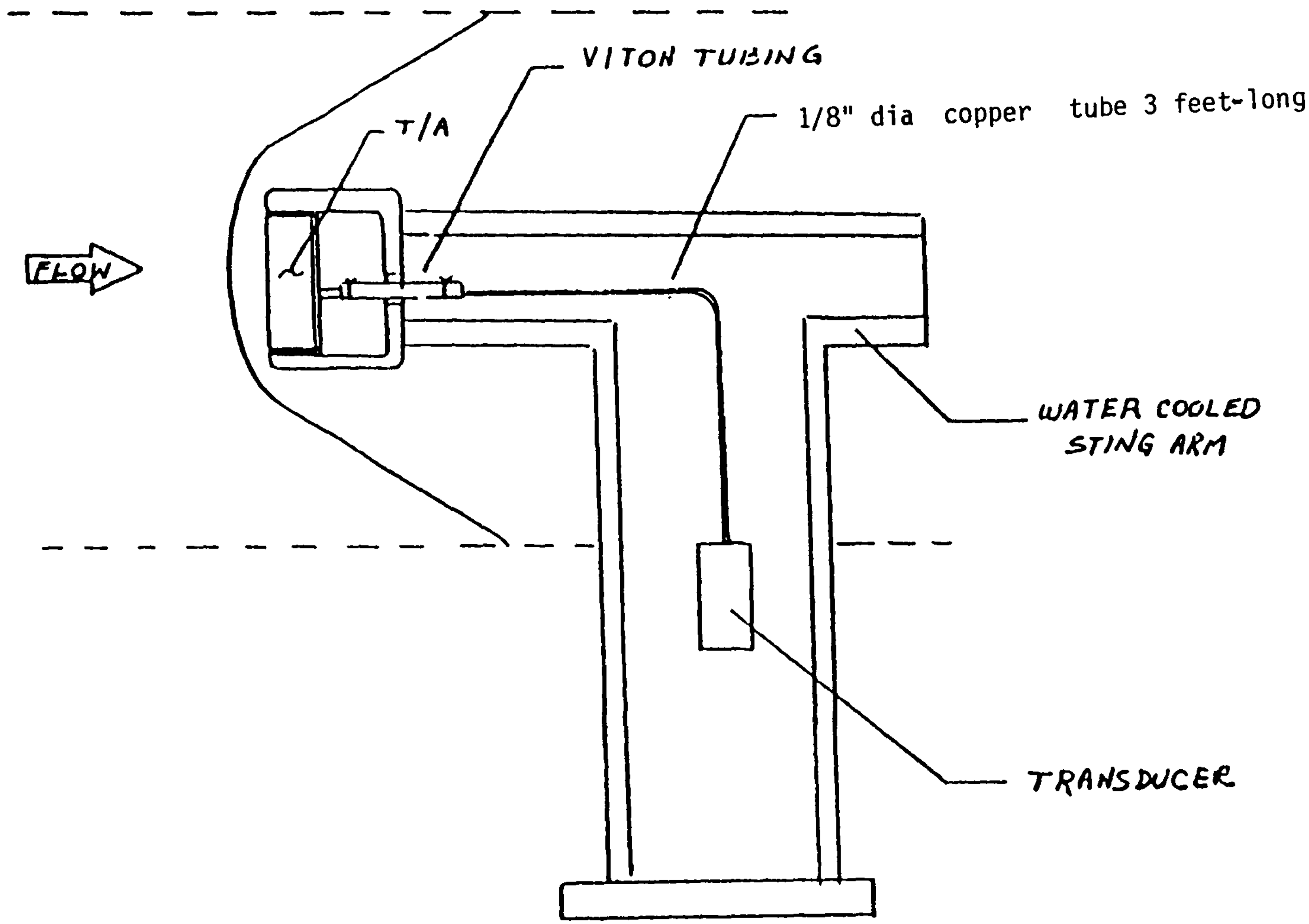
Figure 17 Pretest 3-F12FB-159, 2700 degrees F fully bonded, front view

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH



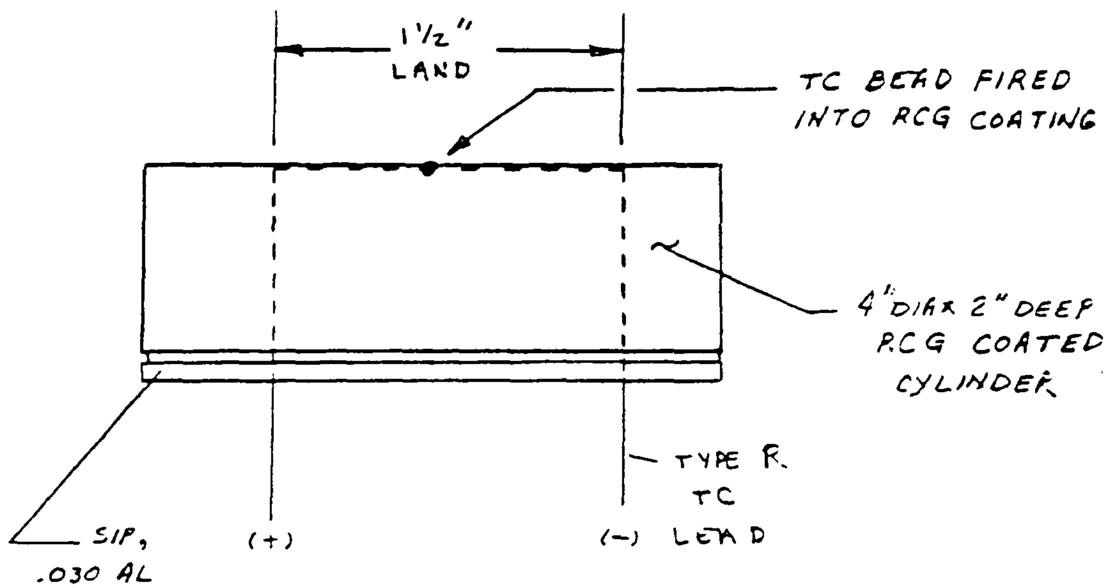
PD/ADS PRESSURE PORT TEST ARTICLE ARC-JET FACILITY INSTALLATION

FIGURE 18



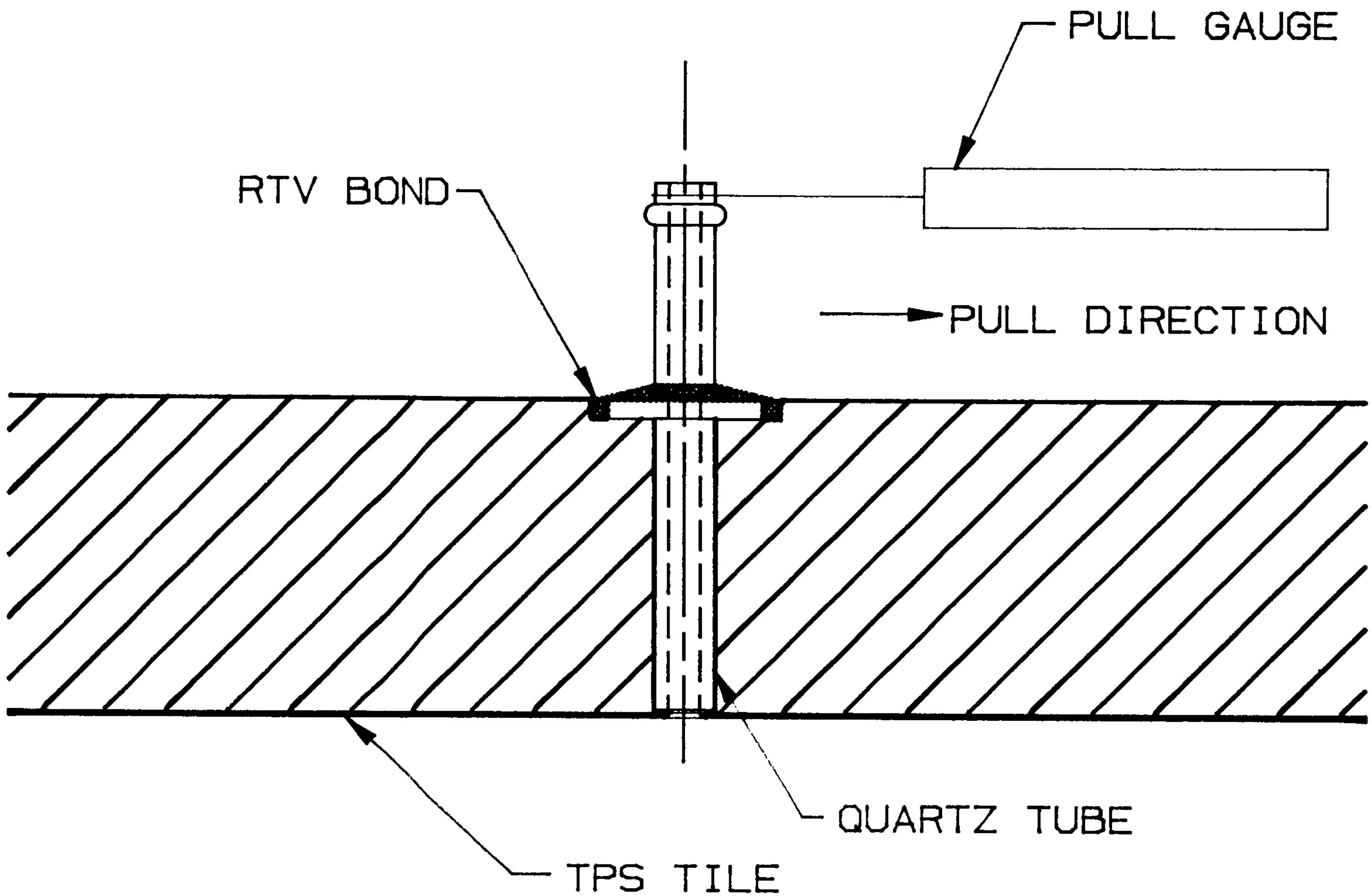
ROUTING OF TEST ARTICLE PRESSURE LINE

Figure 19



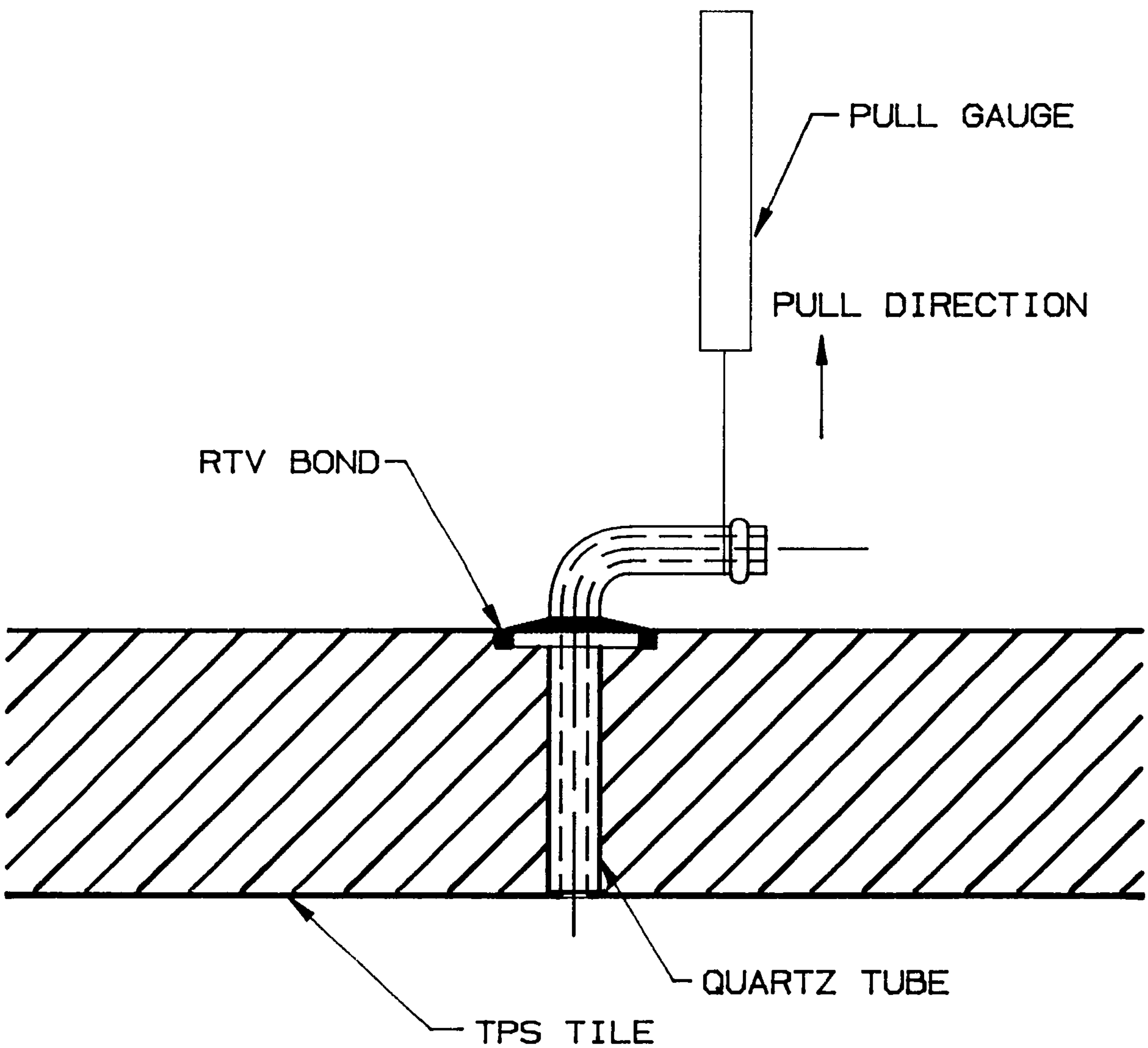
CONSTRUCTION OF CALIBRATION MODEL, SHOWING THERMOCOUPLE INSTALLATION TECHNIQUE

Figure 20



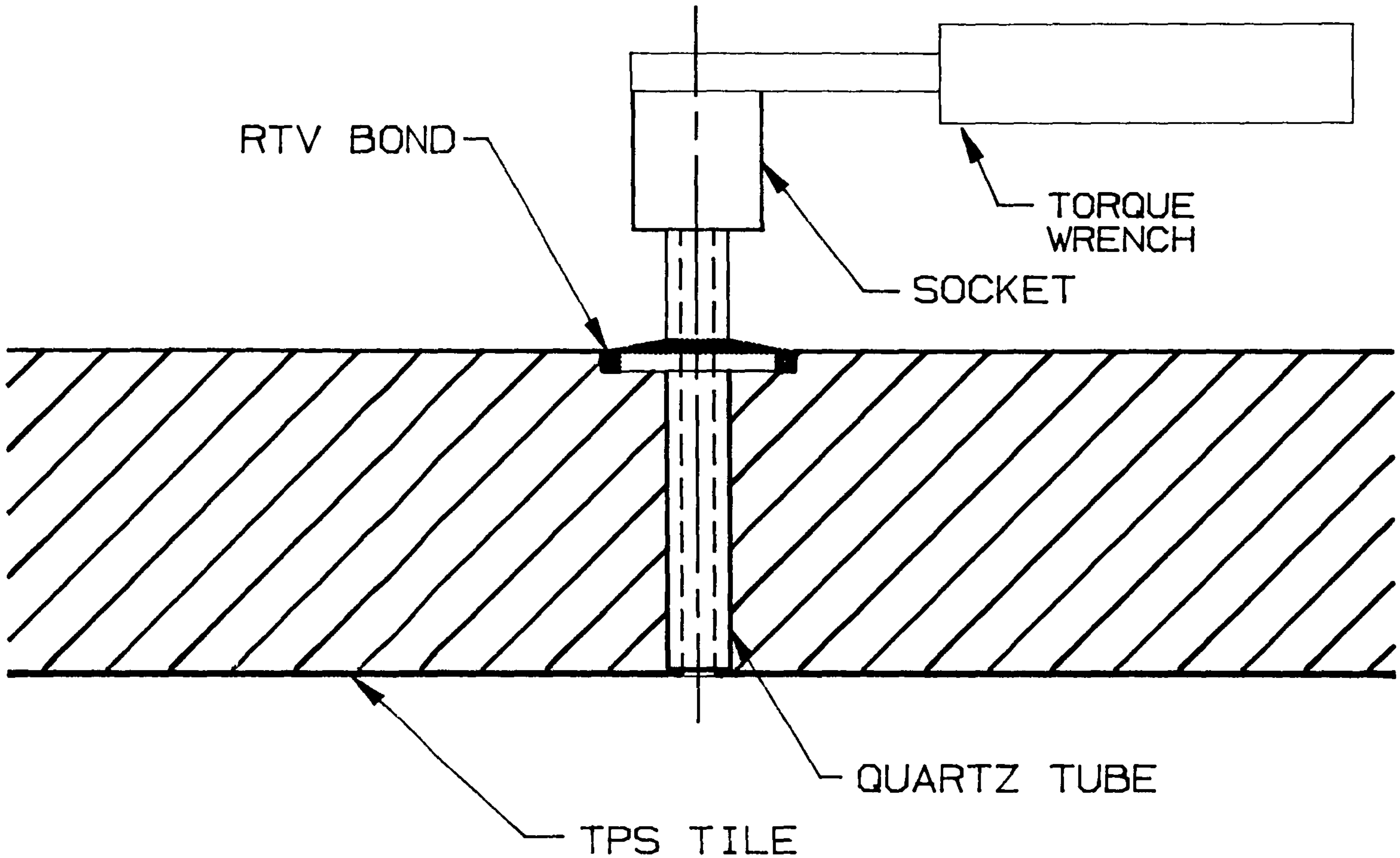
BENDING TEST ARTICLE

FIGURE 21



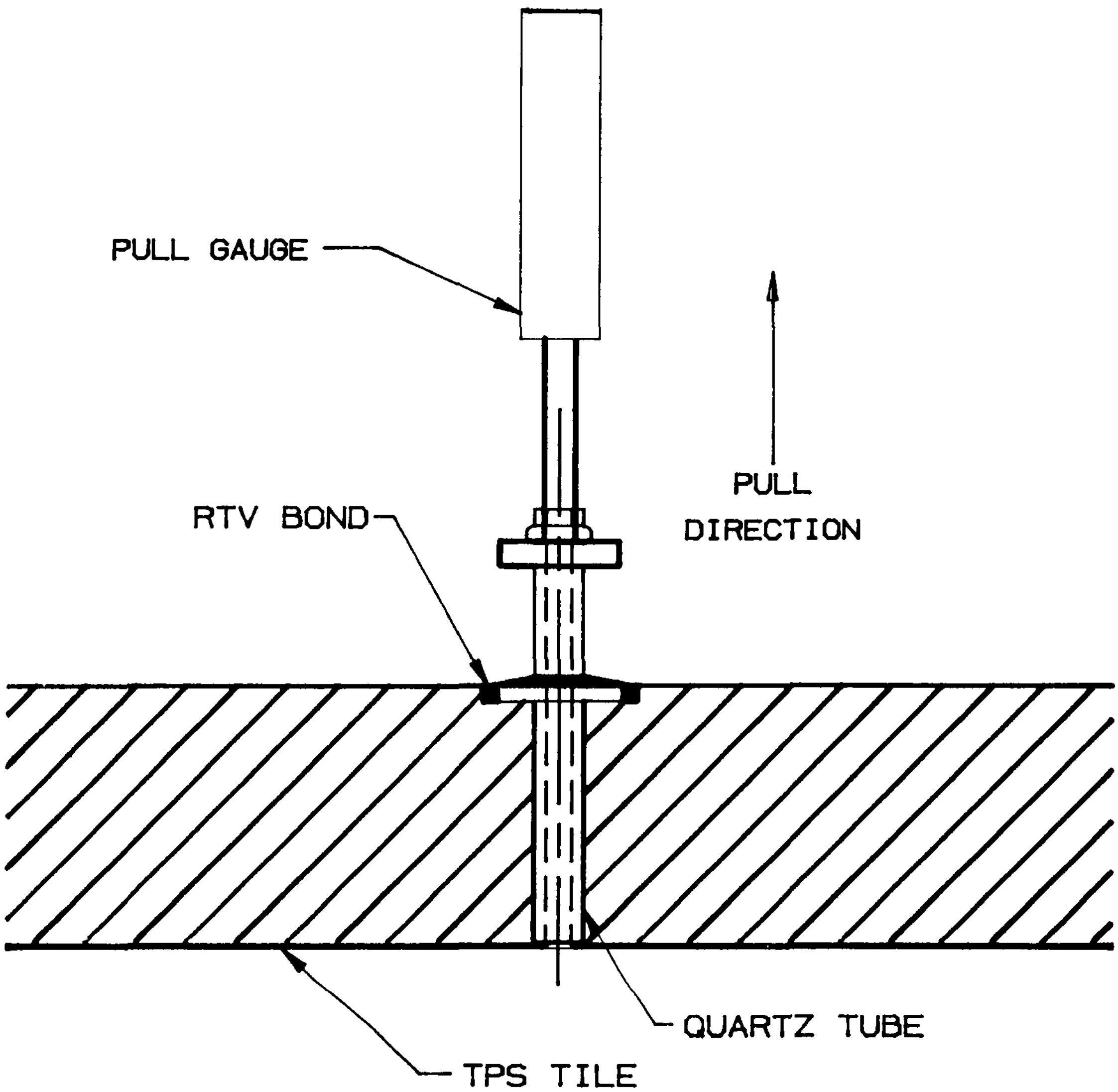
BENDING TEST ARTICLE

FIGURE 22



TORQUE TEST ARTICLE

FIGURE 23



PULL TEST ARTICLE

FIGURE 24

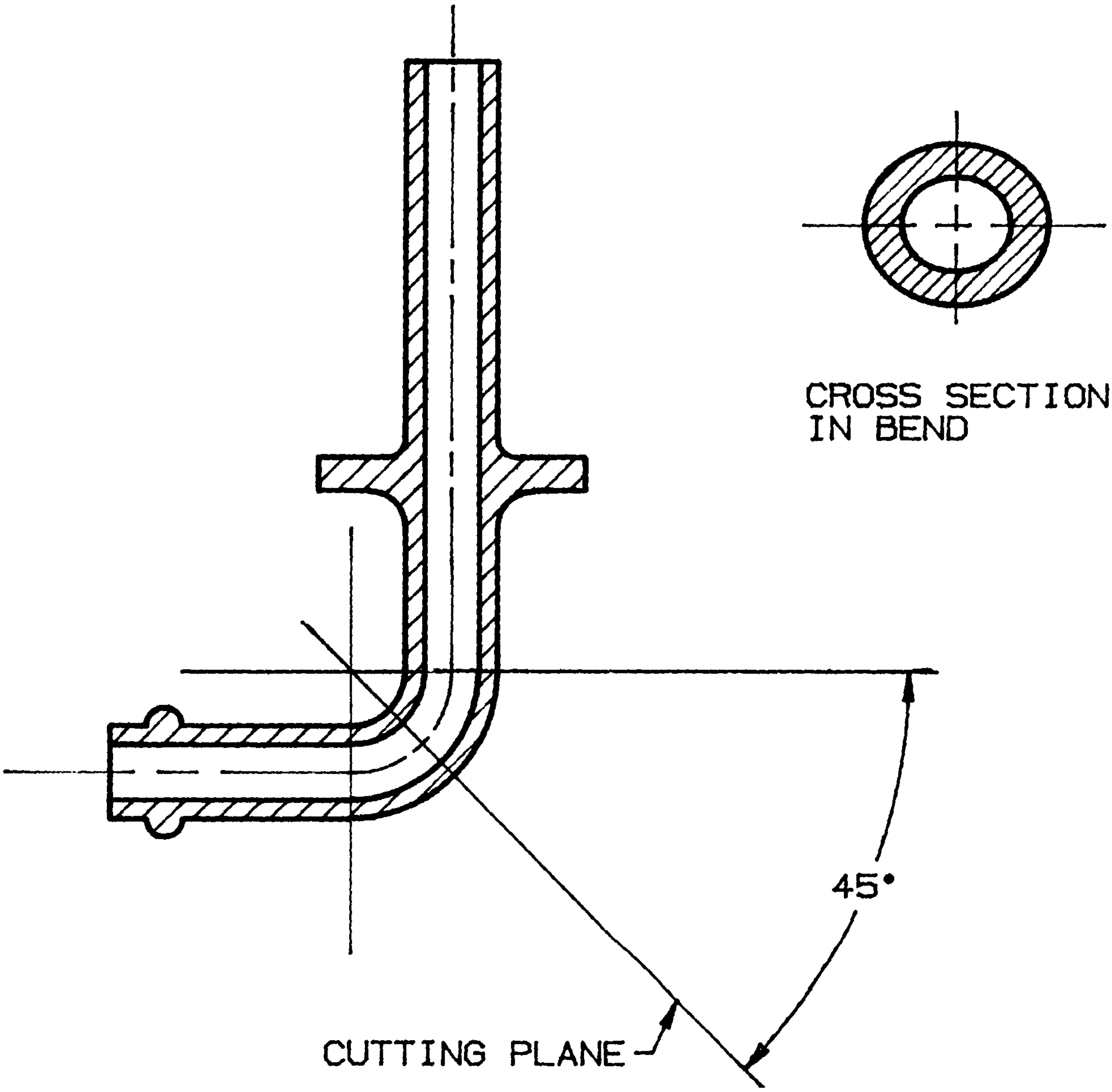


Figure 25 Tube, Bent Cross-Section

NASA-S-74-5037

JSC 10Mw ARMSEF (ATMOSPHERIC REENTRY MATERIALS AND STRUCTURES EVALUATION FACILITY) BUILDING 222

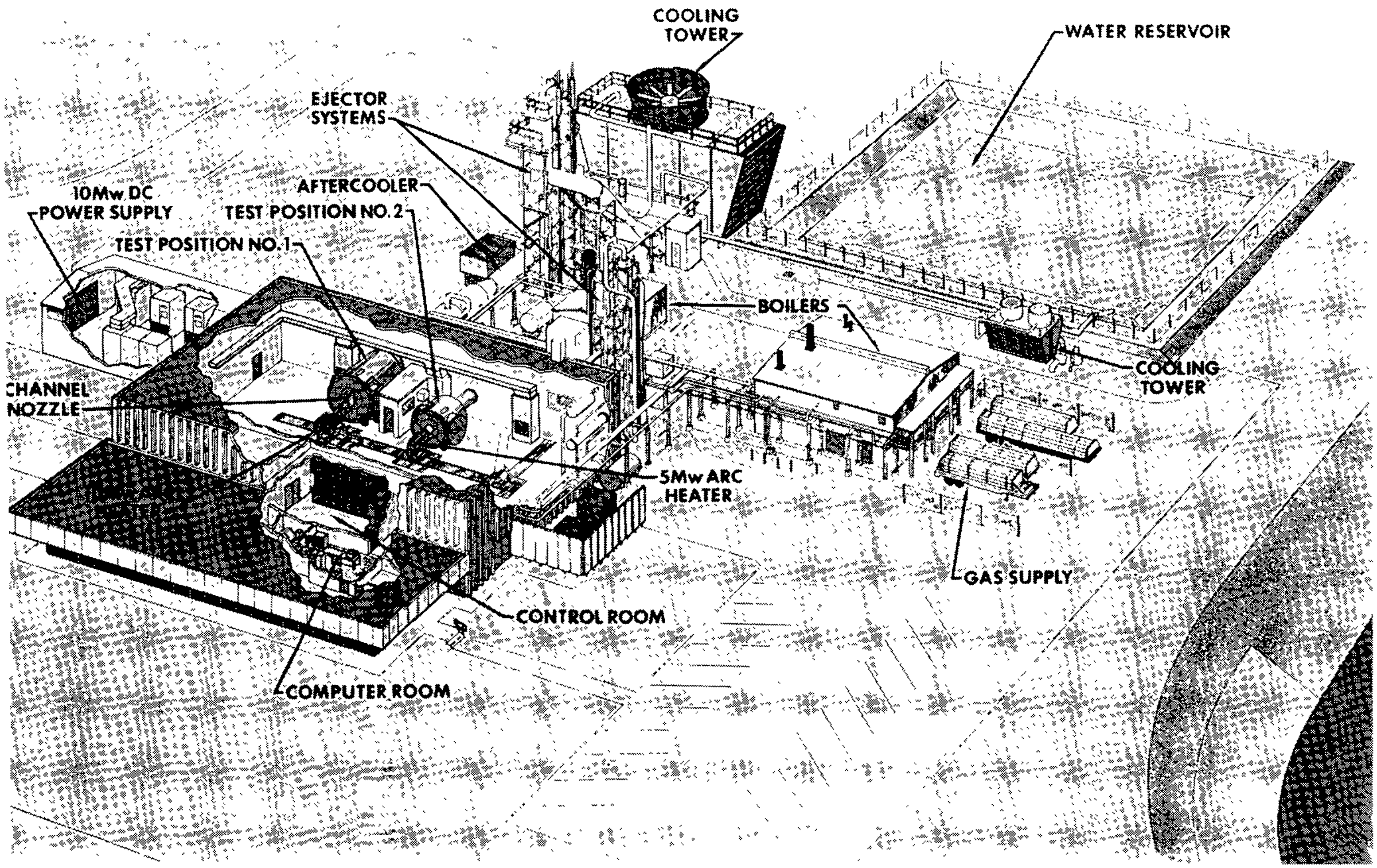
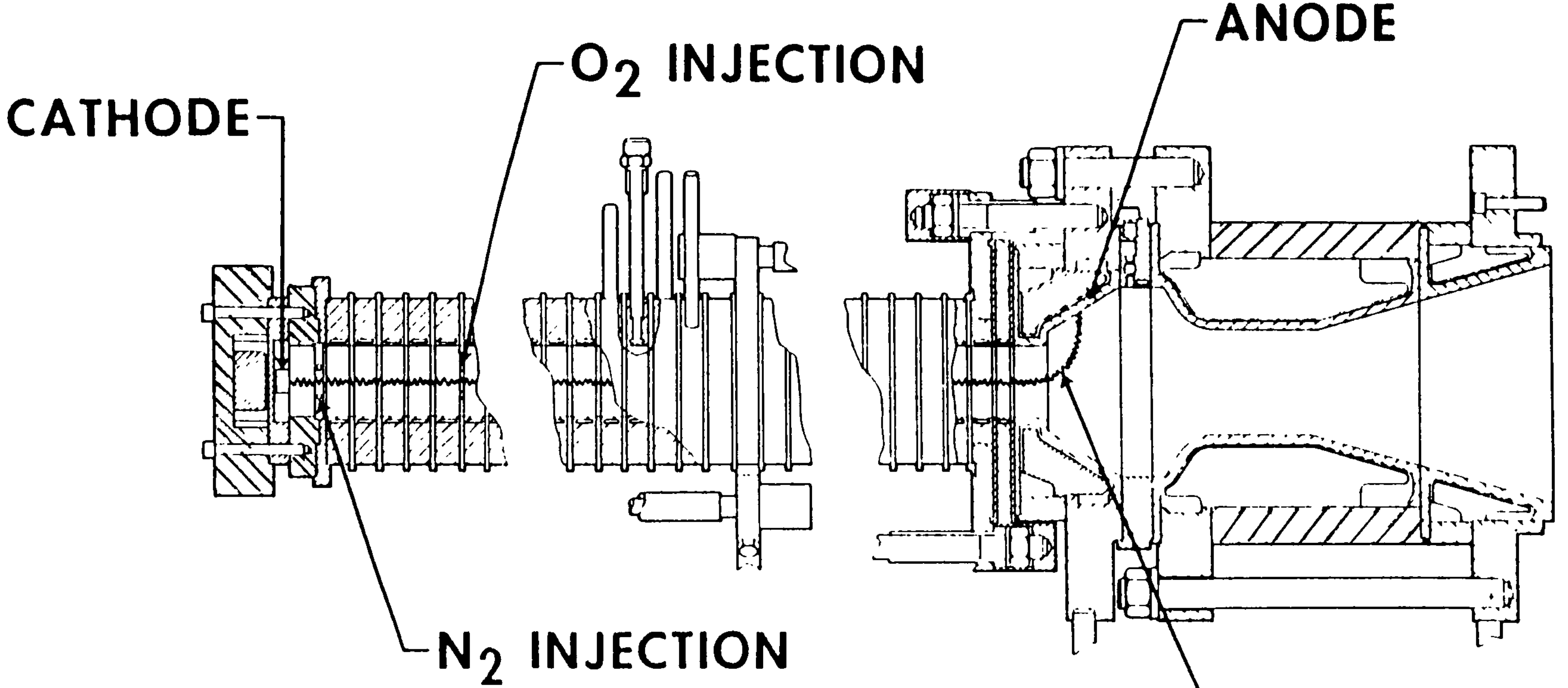


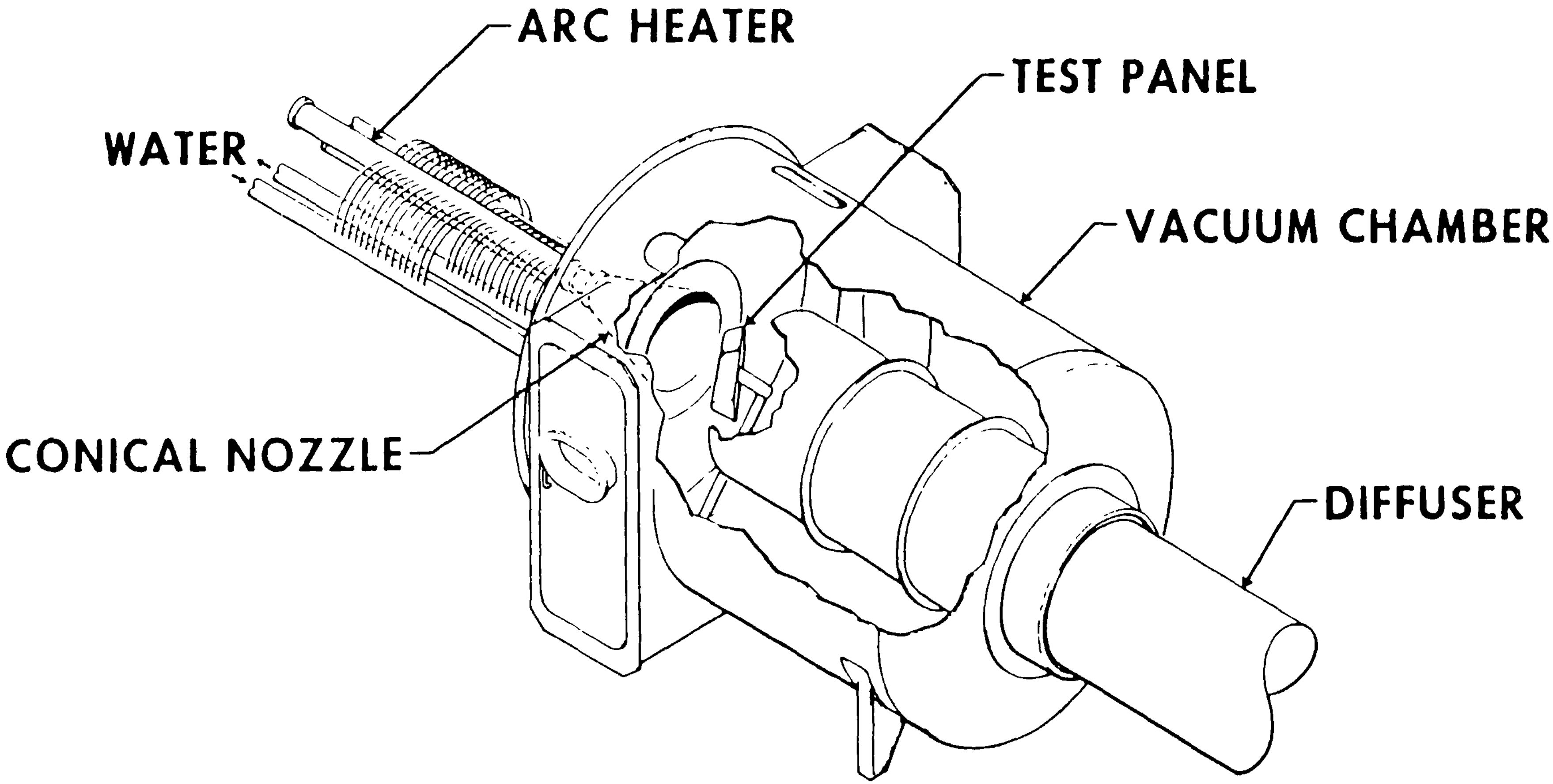
Figure 26 Arc-Jet Test Facility, showing Test Position No. 1 & No. 2



Cutaway View of 10 Mw Arc Heater, Showing Electrodes and Arc Column

Figure 27

CONICAL NOZZLE TEST TECHNIQUE



Cutaway View of Test Chamber, Showing Typical Test Setup

Figure 28

RANDOM SPECTRA FOR A.F.E.

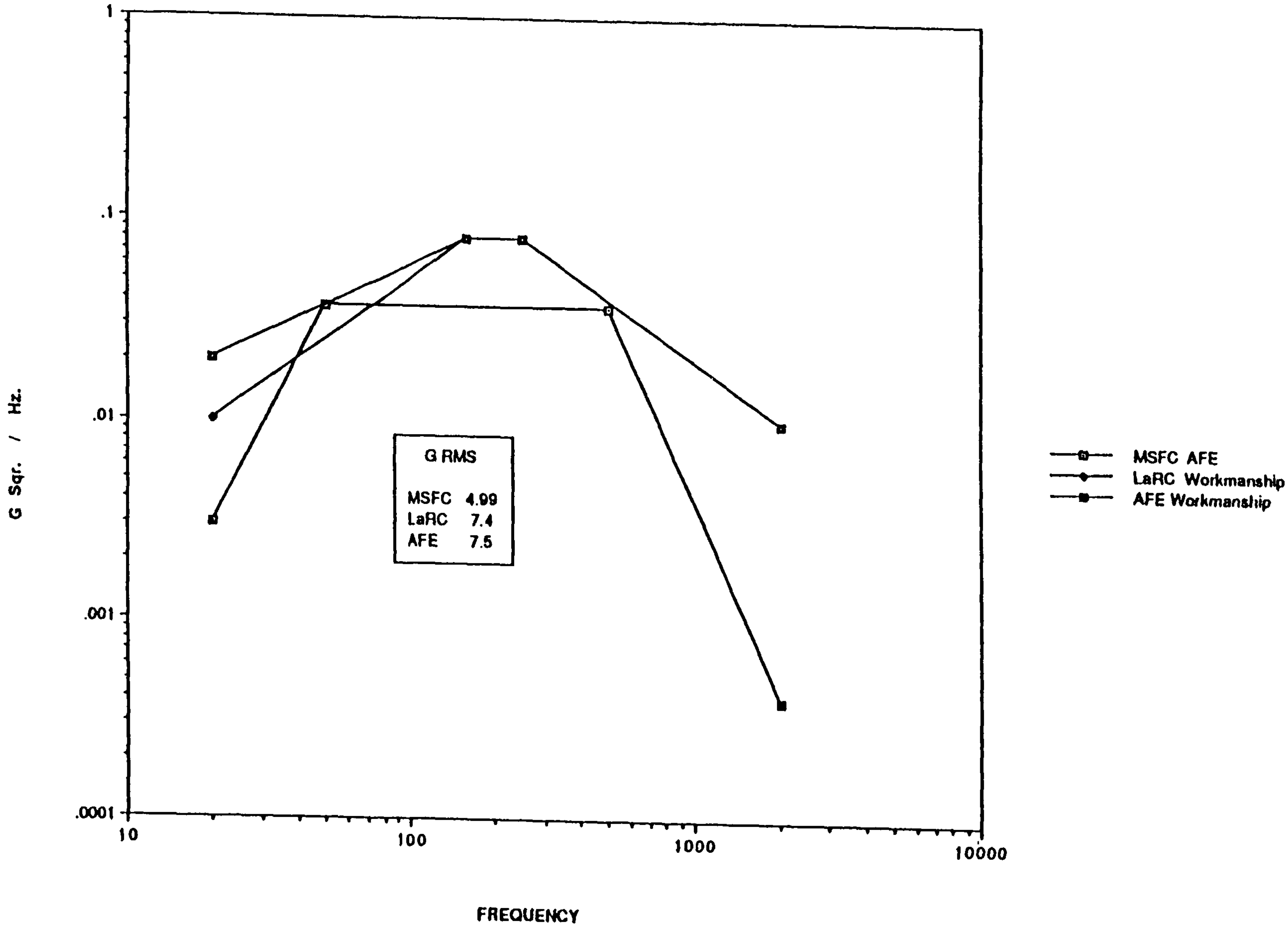


Figure 29A

RANDOM VIBRATION TEST SPECTRUM - TYPICAL RANDOM TEST RUNS 3, 4, 5

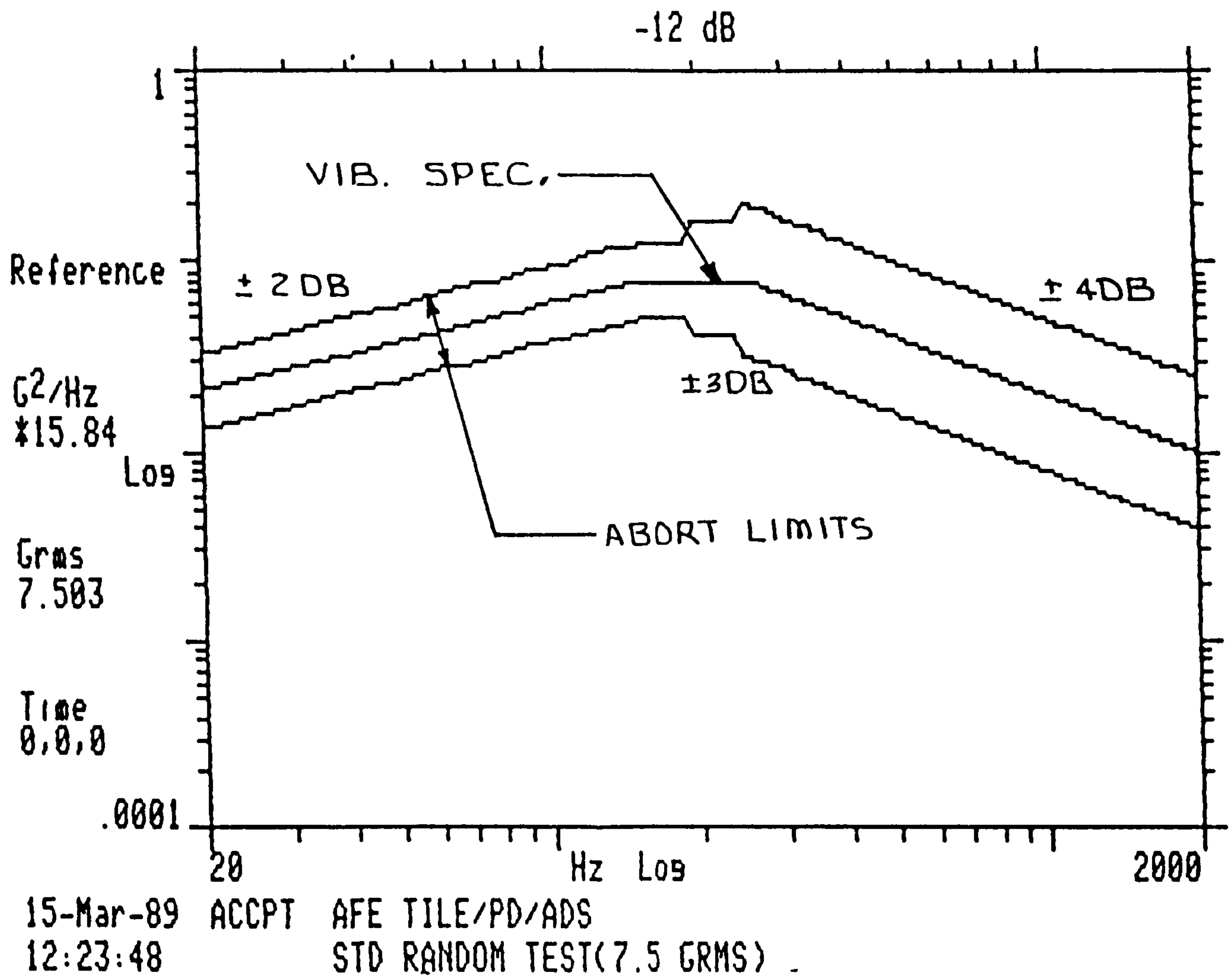


Figure 29B

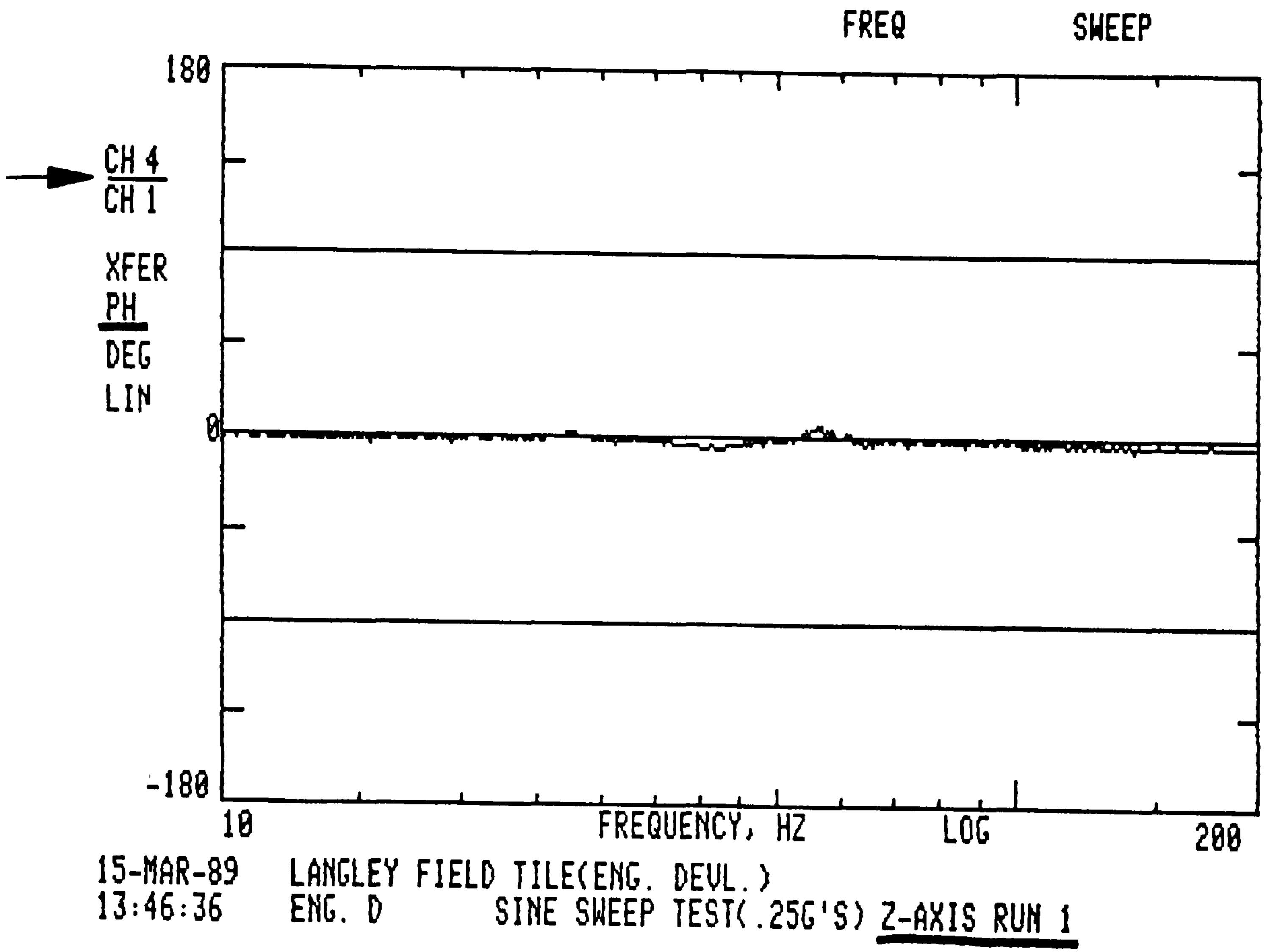

FREQ SWEEP
180
CH 4
CH 1
XFER
PH
DEG
LIN
0
-180
10
FREQUENCY, HZ
LOG
200
15-MAR-89 LANGLEY FIELD TILE(ENG. DEVL.)
13:46:36 ENG. D SINE SWEEP TEST(.25G'S) Z-AXIS RUN 1

Figure 30

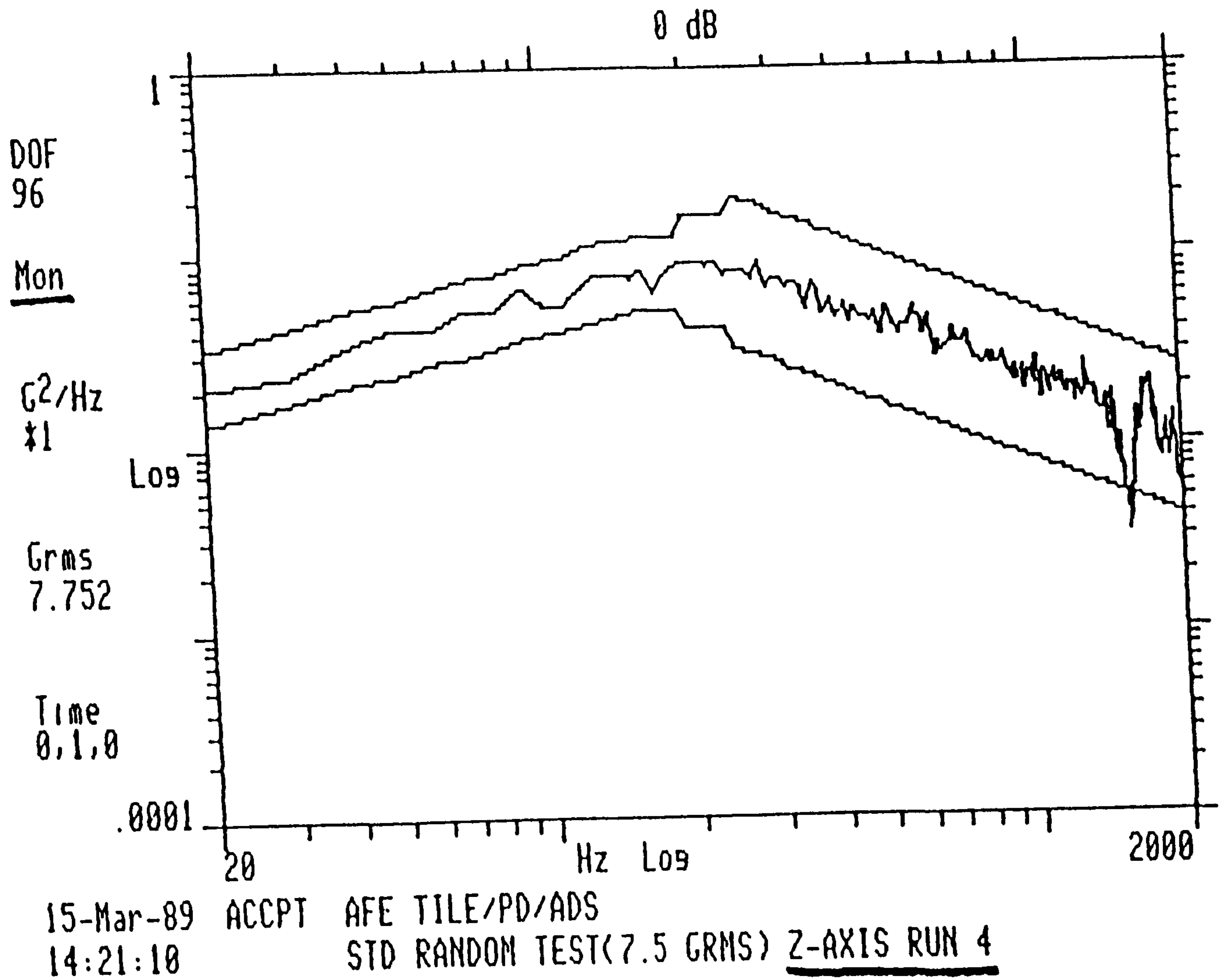

0 dB
1
DOF
96
Mon
G2/Hz
*1
Log
Grms
7.752
Time
0,1,0
.0001
20
Hz Log
2000
15-Mar-89 ACCPT AFE TILE/PD/ADS
14:21:10 STD RANDOM TEST(7.5 GRMS) Z-AXIS RUN 4

Figure 31

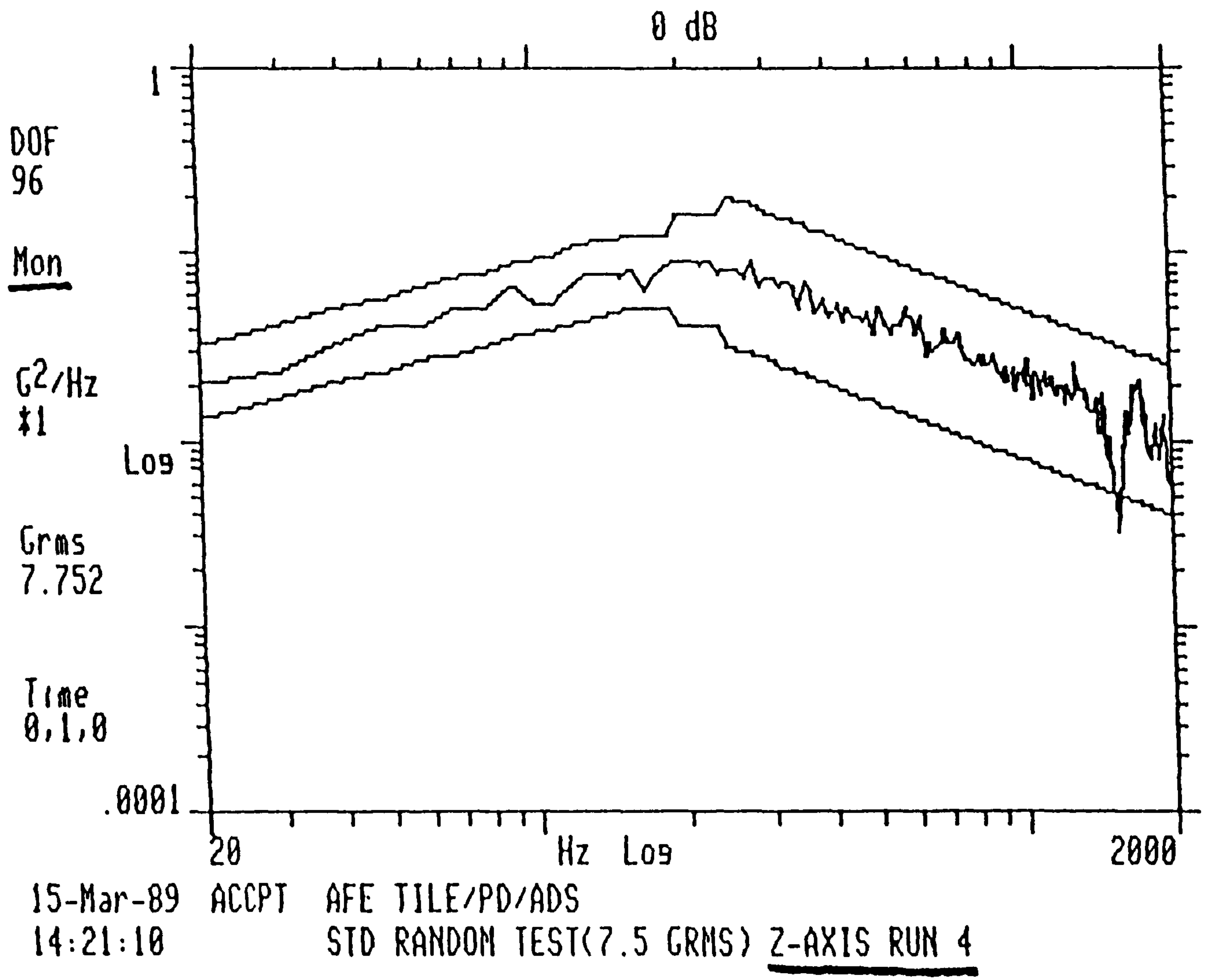

0 dB
1
DOF
96
Mon
G²/Hz
*1
Log
Grms
7.752
Time
0,1,0
.0001
20
Hz Log
2000
15-Mar-89 ACCPT AFE TILE/PD/ADS
14:21:10 STD RANDOM TEST(7.5 GRMS) Z-AXIS RUN 4

Figure 31

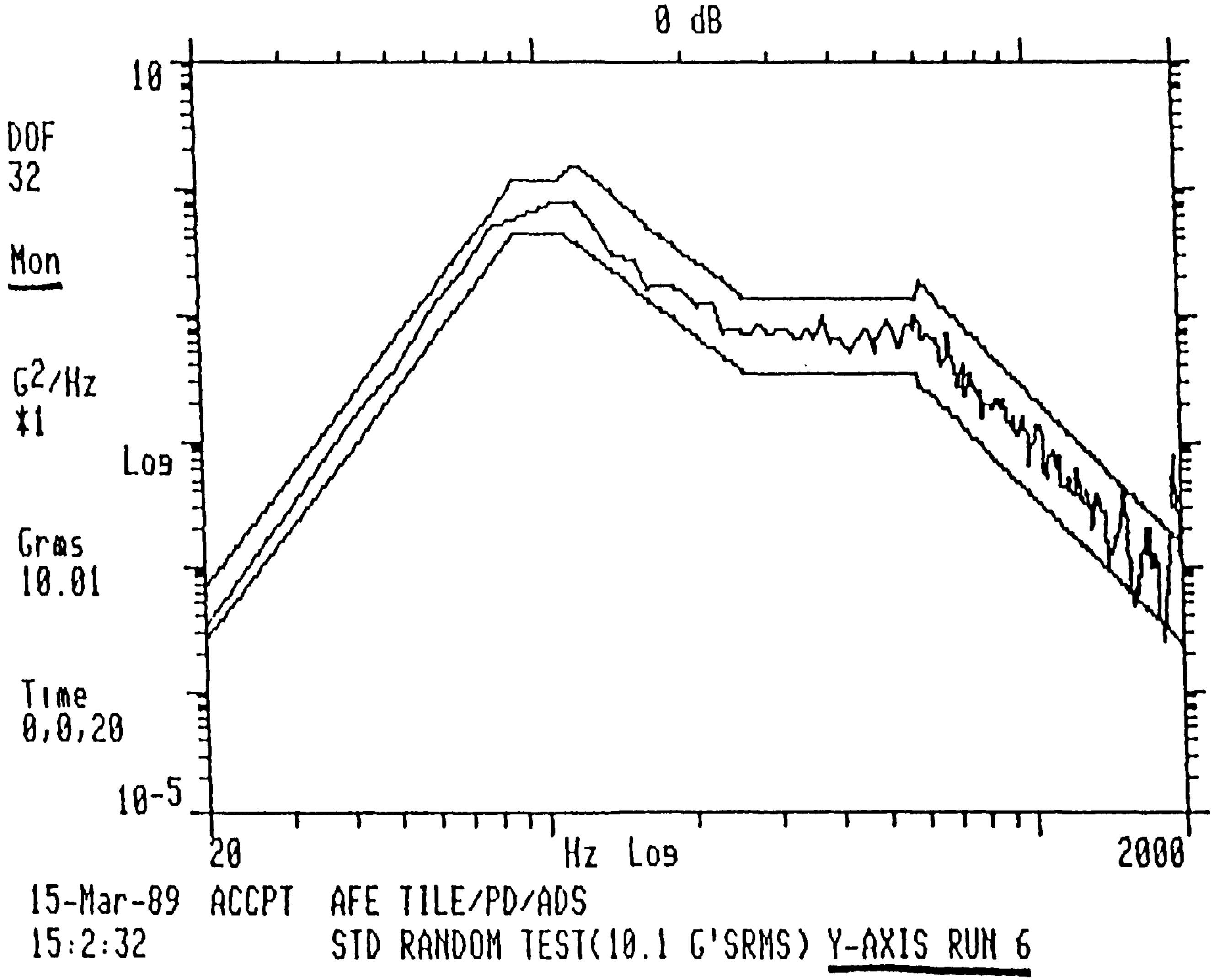

0 dB
10
DOF
32
Mon
G2/Hz
*1
Log
Grms
10.01
Time
0,0,20
10-5
20
Hz Log
2000
15-Mar-89 ACCPT AFE TILE/PD/ADS
15:2:32 STD RANDOM TEST(10.1 G'SRMS) Y-AXIS RUN 6

Figure 33

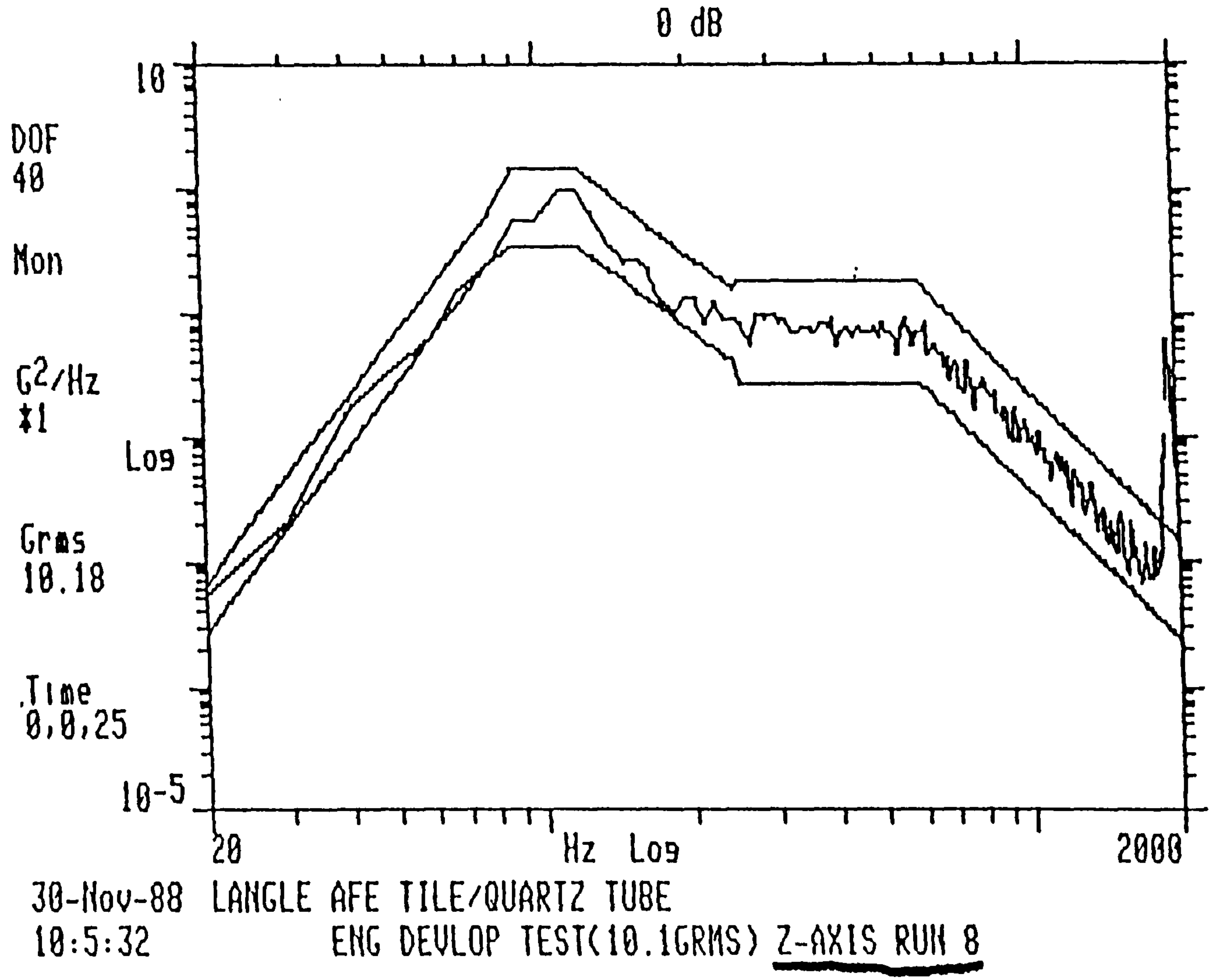

0 dB
10
DOF
40
Mon
G2/Hz
*1
Log
Grms
10.18
Time
0,0,25
10-5
20
Hz Log
2000
30-Nov-88 LANGLE AFE TILE/QUARTZ TUBE
10:5:32 ENG DEVLOP TEST(10.1GRMS) Z-AXIS RUN 8

Figure 34

FINAL TEST SPECTRUM

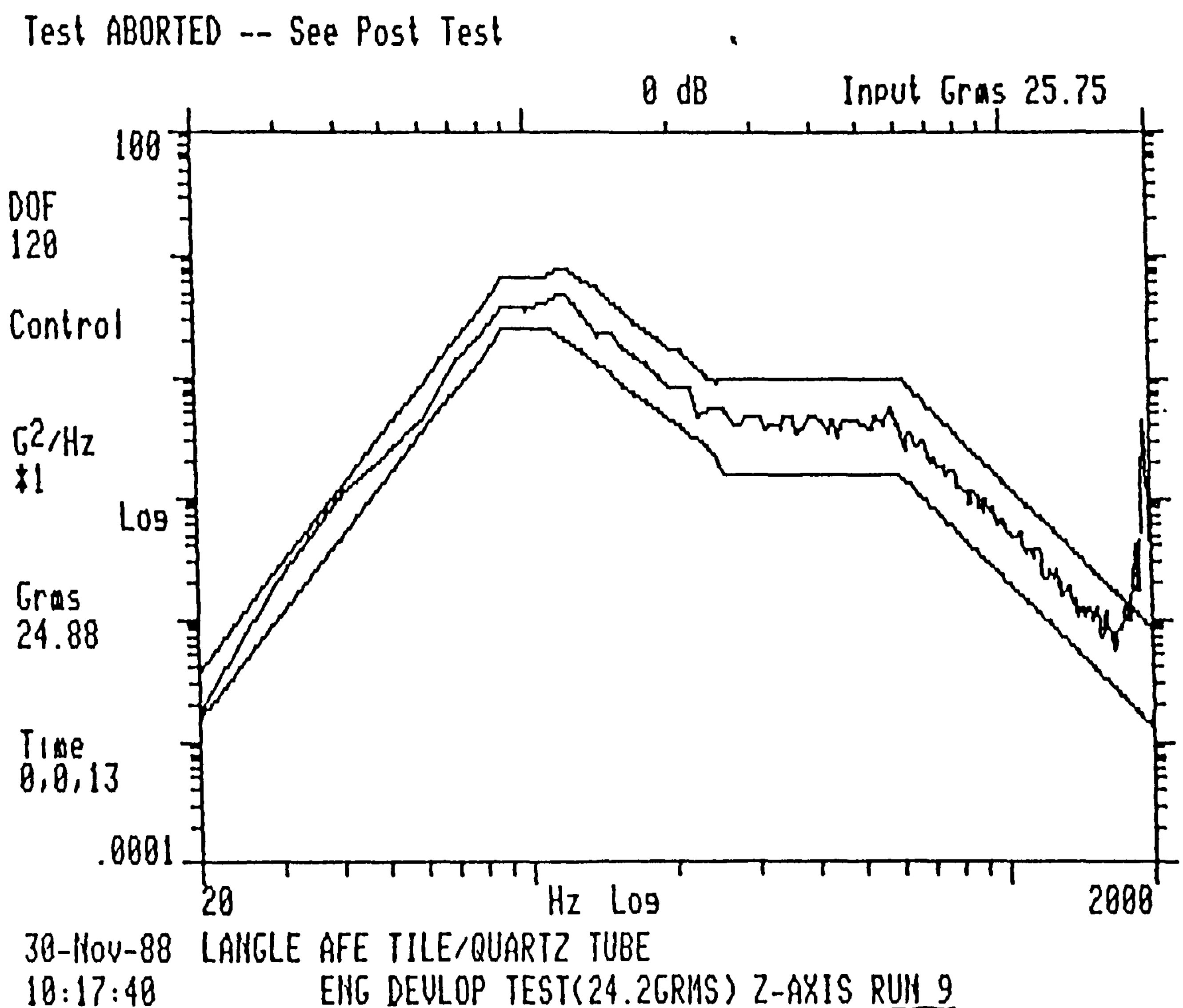


Figure 35

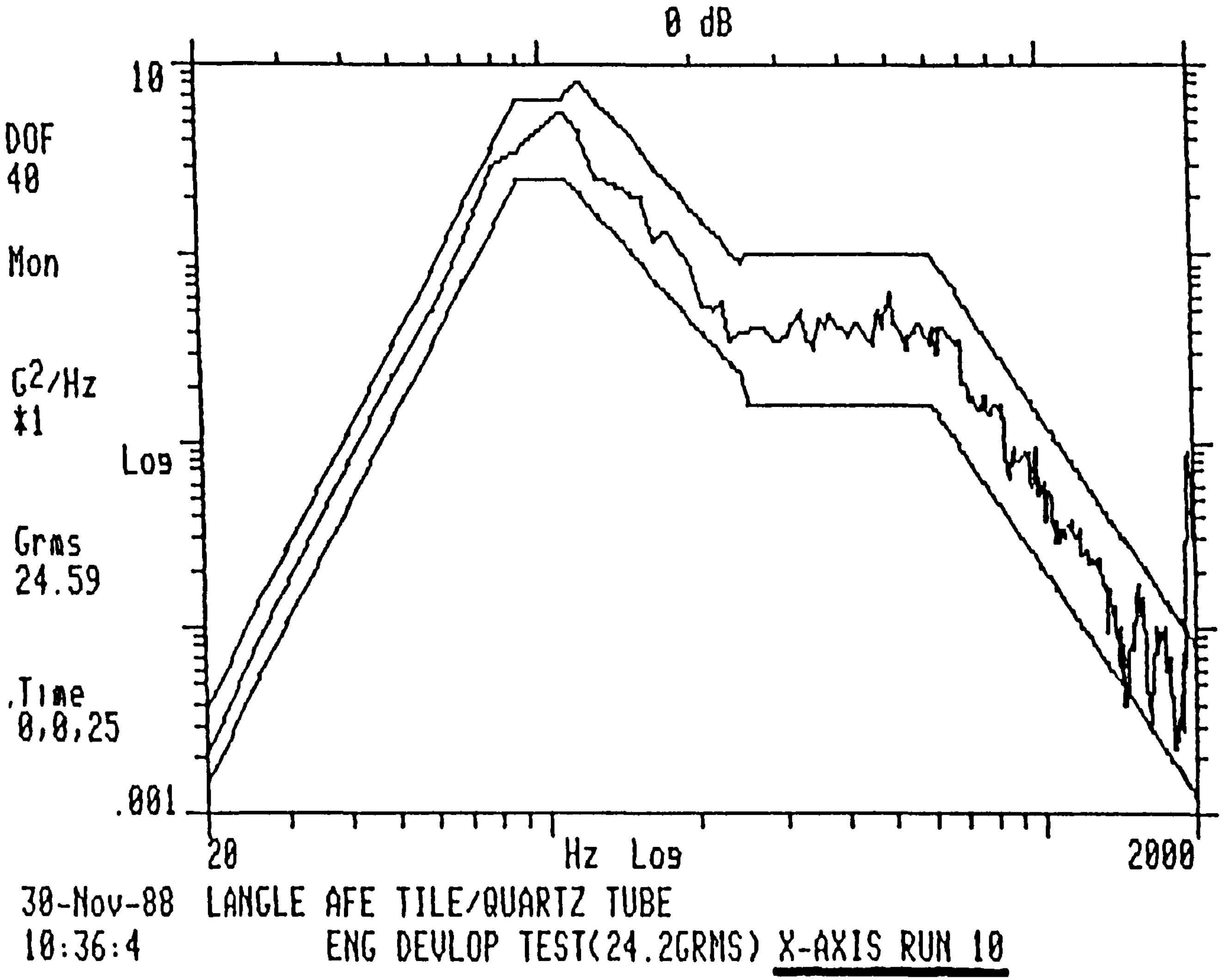

0 dB
10
DOF
40
Mon
G²/Hz
*1
Log
Grms
24.59
Time
0,0,25
.001
20
Hz Log
2000
30-Nov-88 LANGLE AFE TILE/QUARTZ TUBE
10:36:4 ENG DEVLOP TEST(24.2GRMS) X-AXIS RUN 10

Figure 36

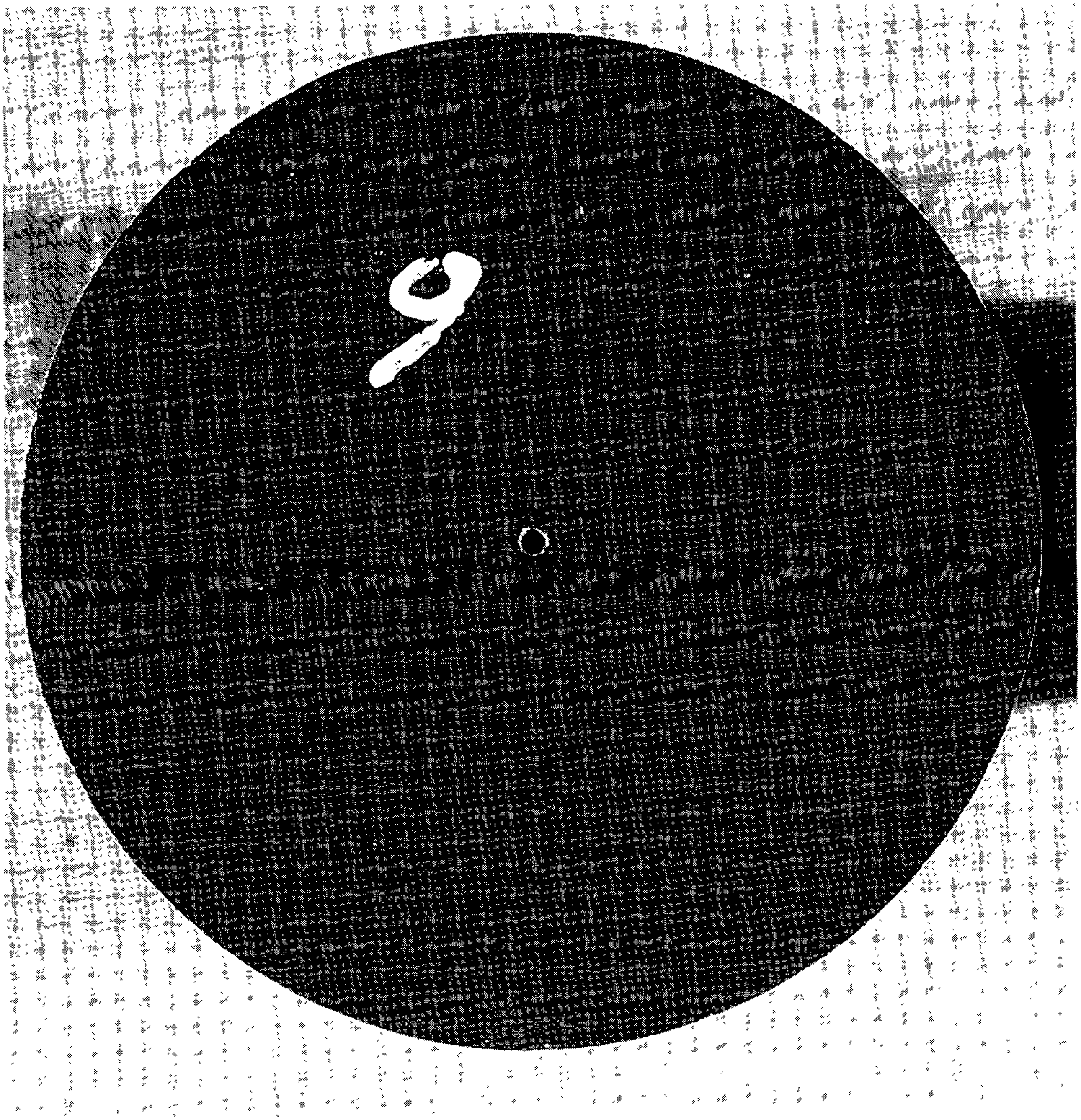


Figure 37 Pretest 1-L9FB-157, 2300 degrees F fully bonded, front view

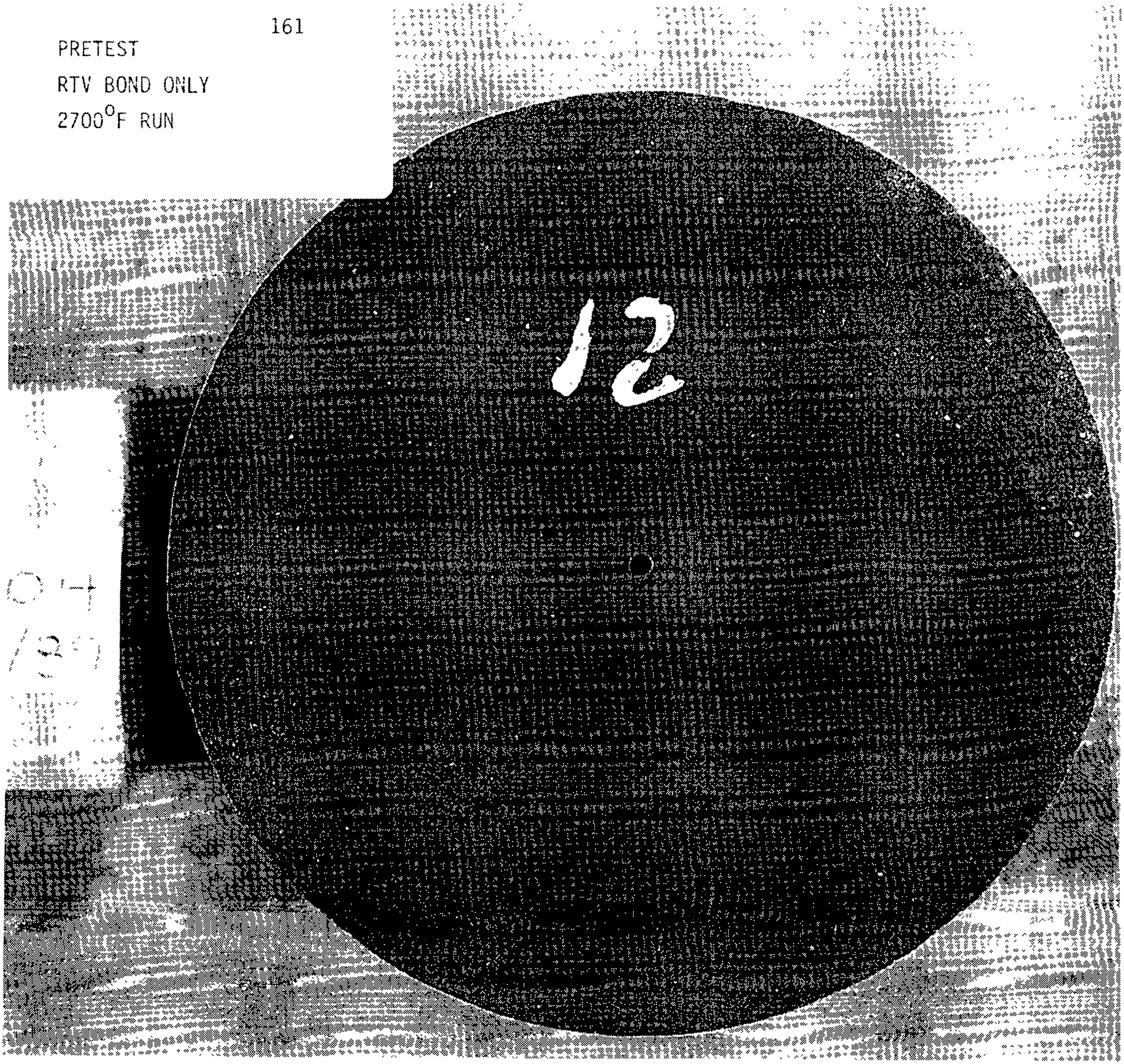


Figure 38 **Pretest 5-F12-161, 2700 degrees F partially bonded, front view**

Figure 39 Pretest 4-F12FB-160, 2800 degrees F fully bonded, front view

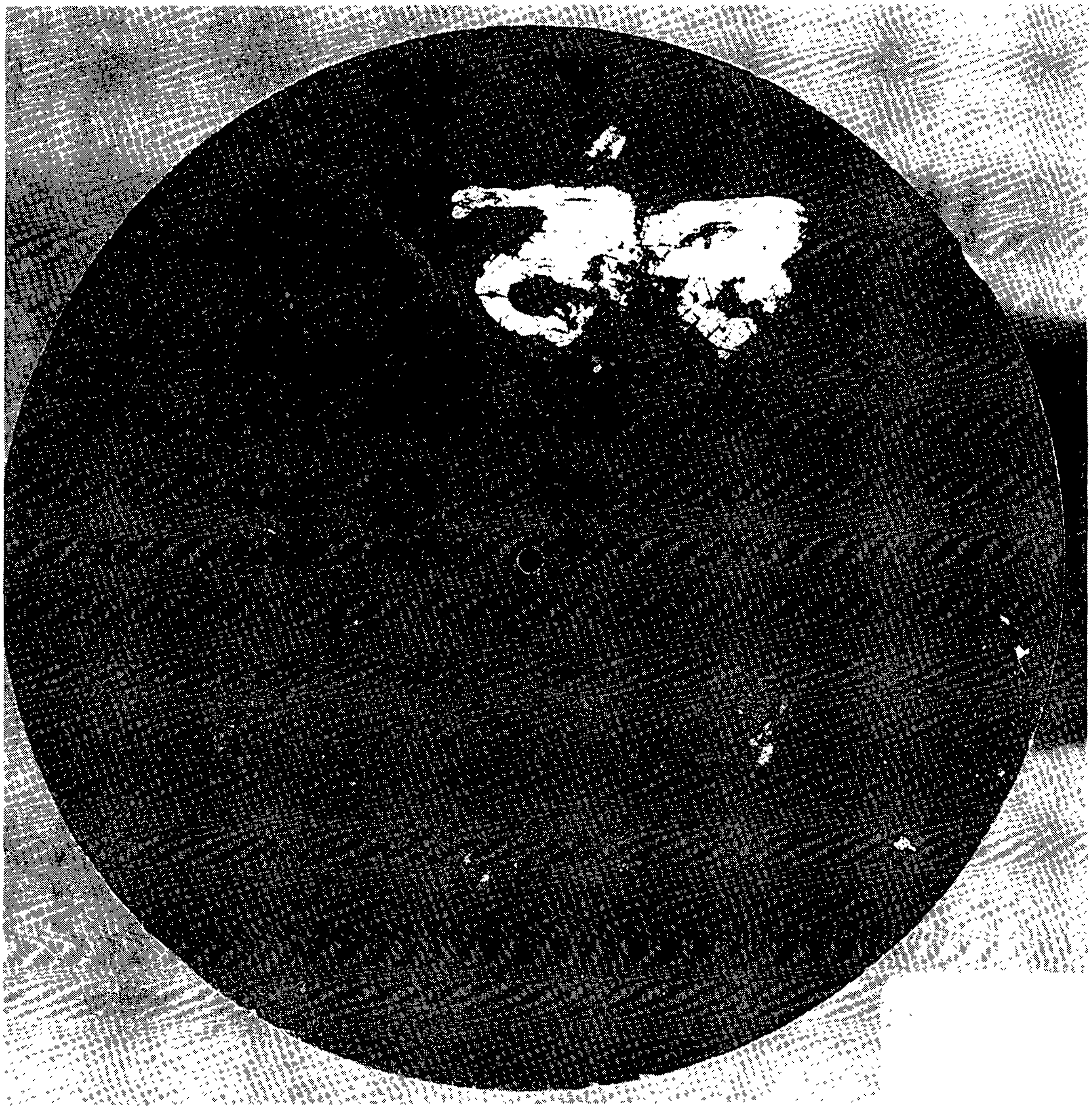


Figure 40 Pretest 2-L22FB-158, 2900 degrees F fully bonded, front view

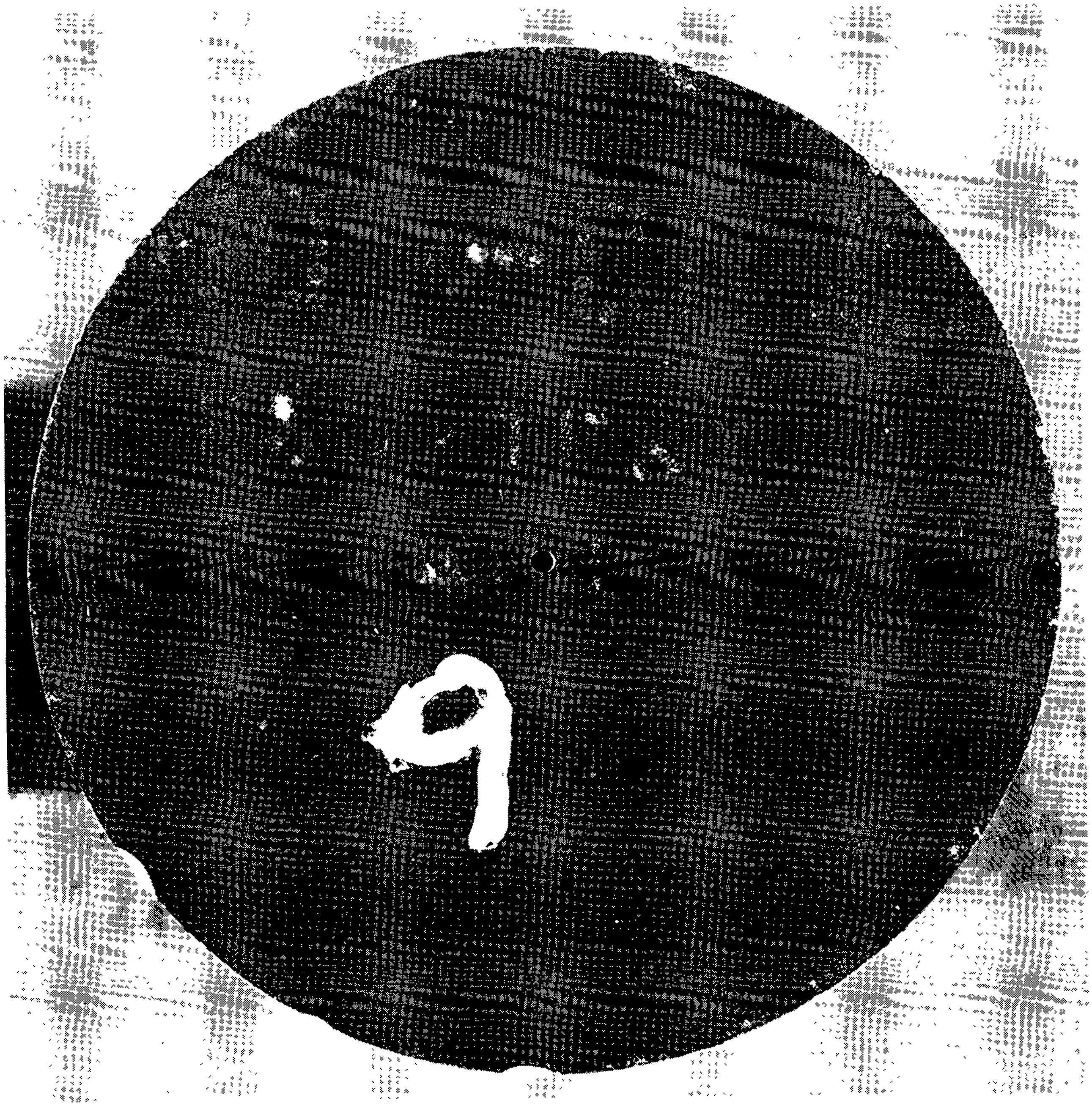


Figure 41 Pretest 6-L9-162, 2300 degrees F partially bonded, front view

Figure 42 Post Test 1-L9FB-157, 2300 degrees F fully bonded, front view

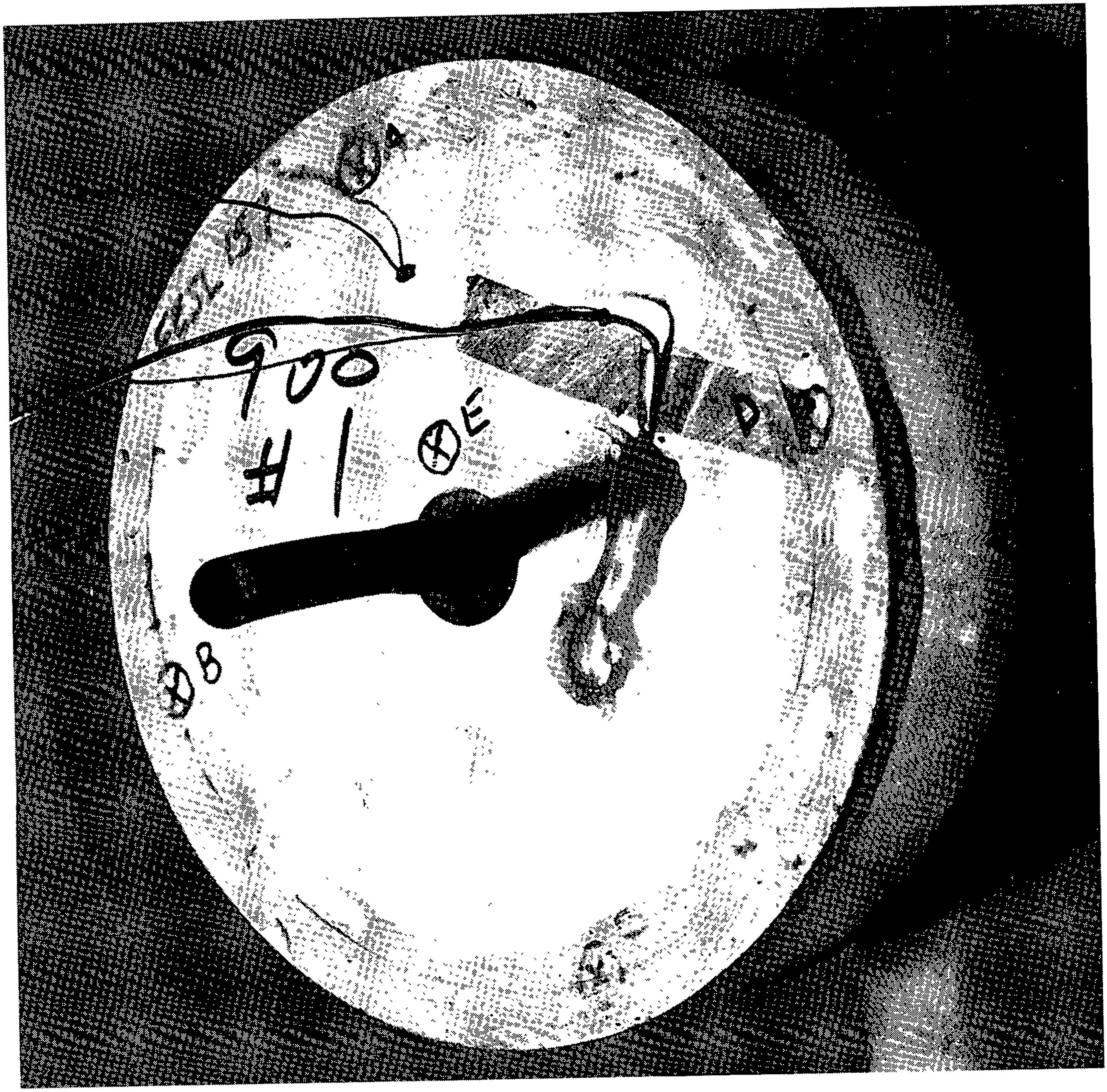


Figure 43 Post Test 1-L9FB-157, 2300 degrees F fully bonded, rear view

Figure 44 Post Test 3-F12FB-159, 2700 degrees F fully bonded, front view

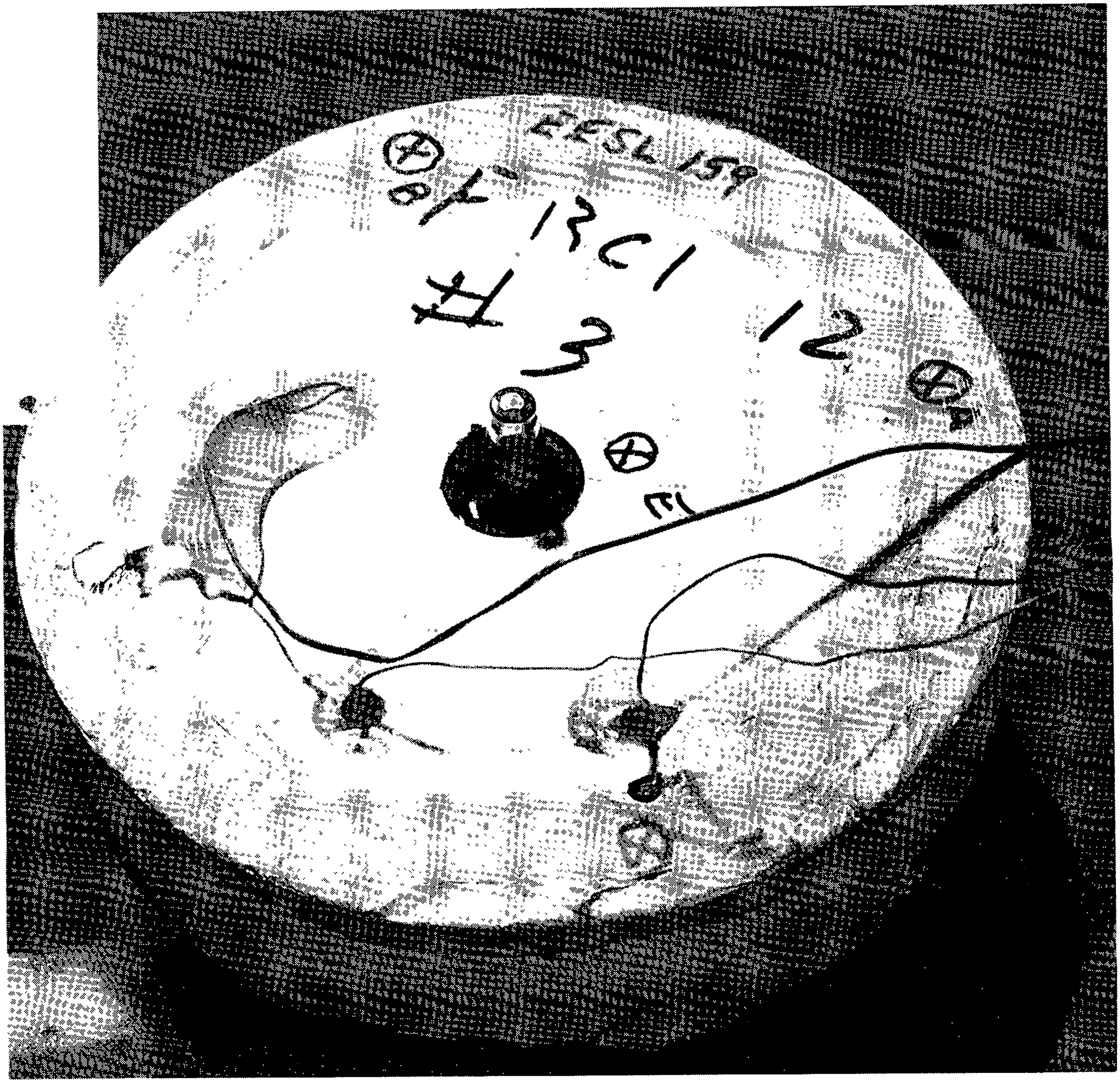


Figure 45 Post Test 3-F12FB-159, 2700 degrees F fully bonded, rear view

Figure 46 Post Test 6-L9-162, 2300 degrees F partially bonded, front view

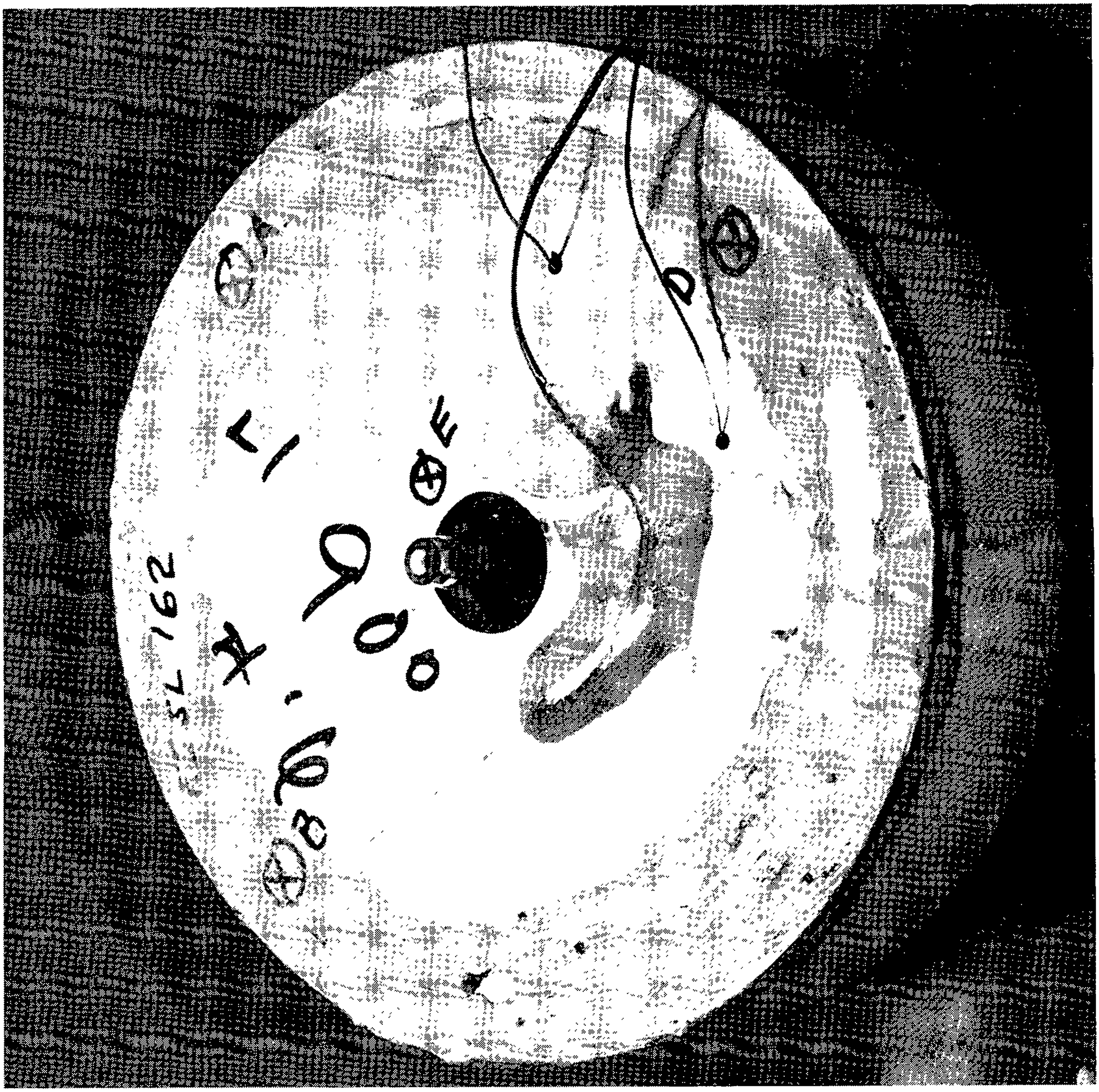
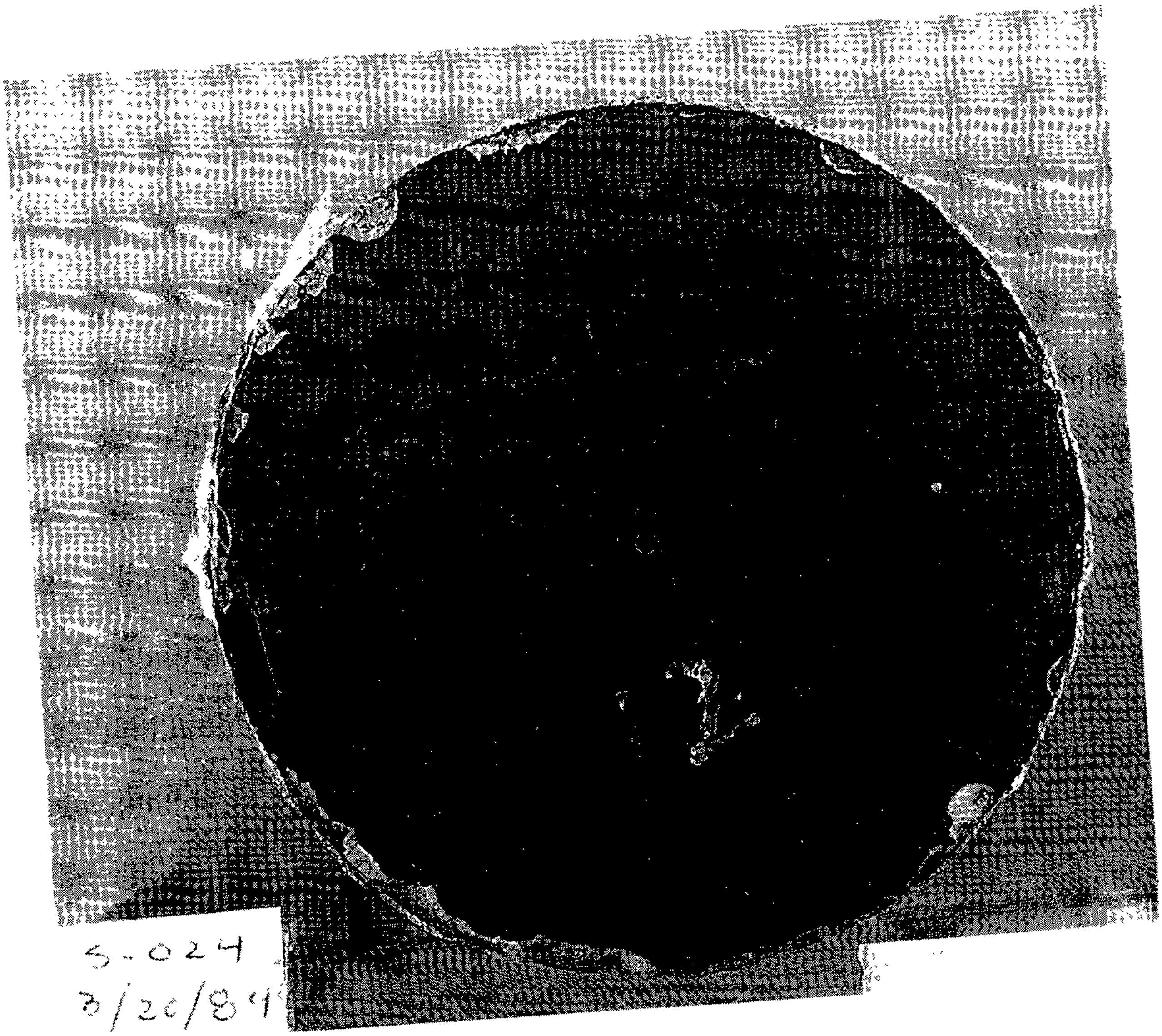


Figure 47 Post Test 6-L9-162, 2300 degrees F partially bonded, rear view



5-024
3/20/89

Figure 49 Post Test 4-F12FB-160, 2800 degrees F fully bonded, front view

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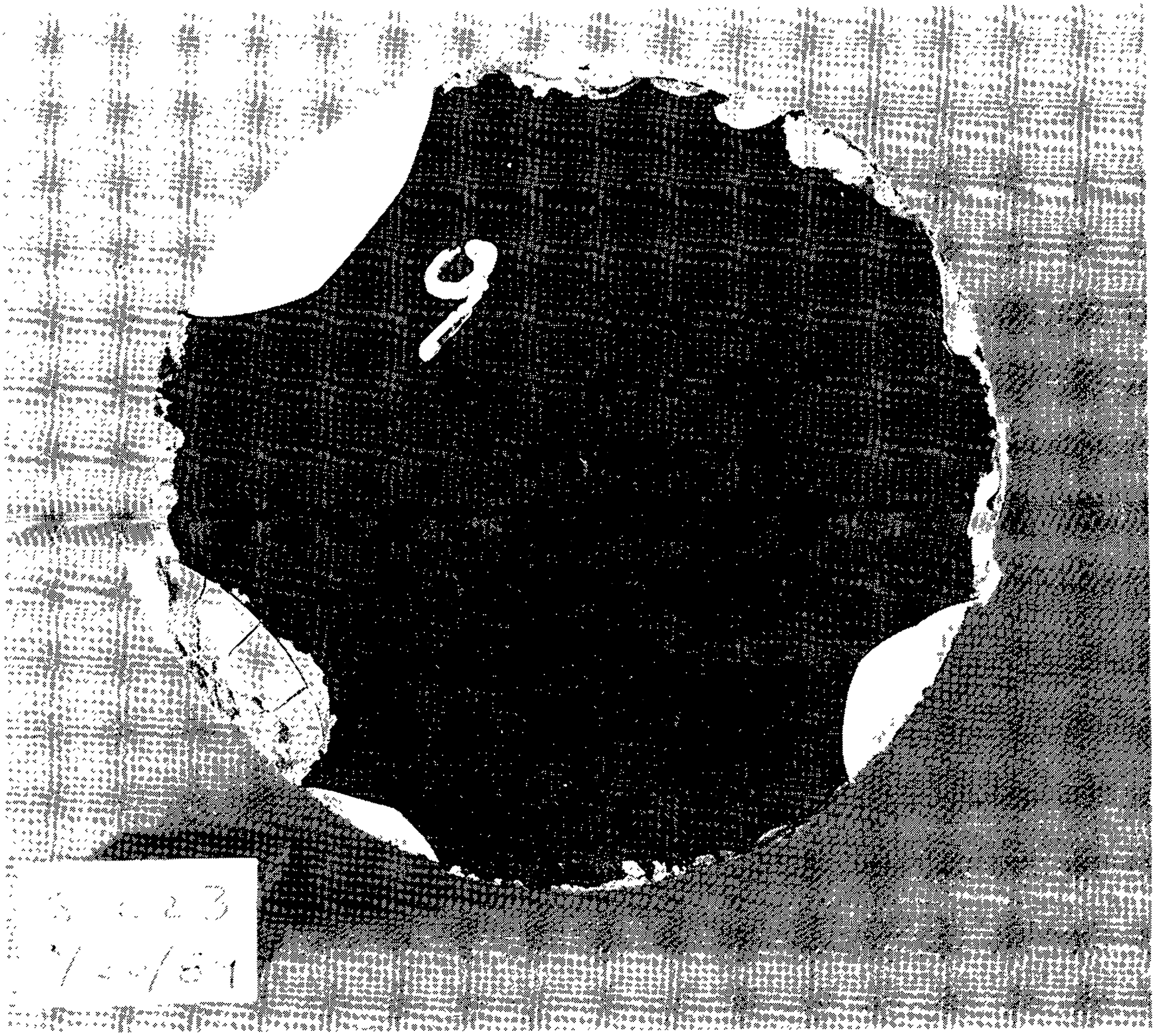

Figure 48 Post Test 1-L9FB-157, 2300 degrees F fully bonded, front view shown after a 2nd run

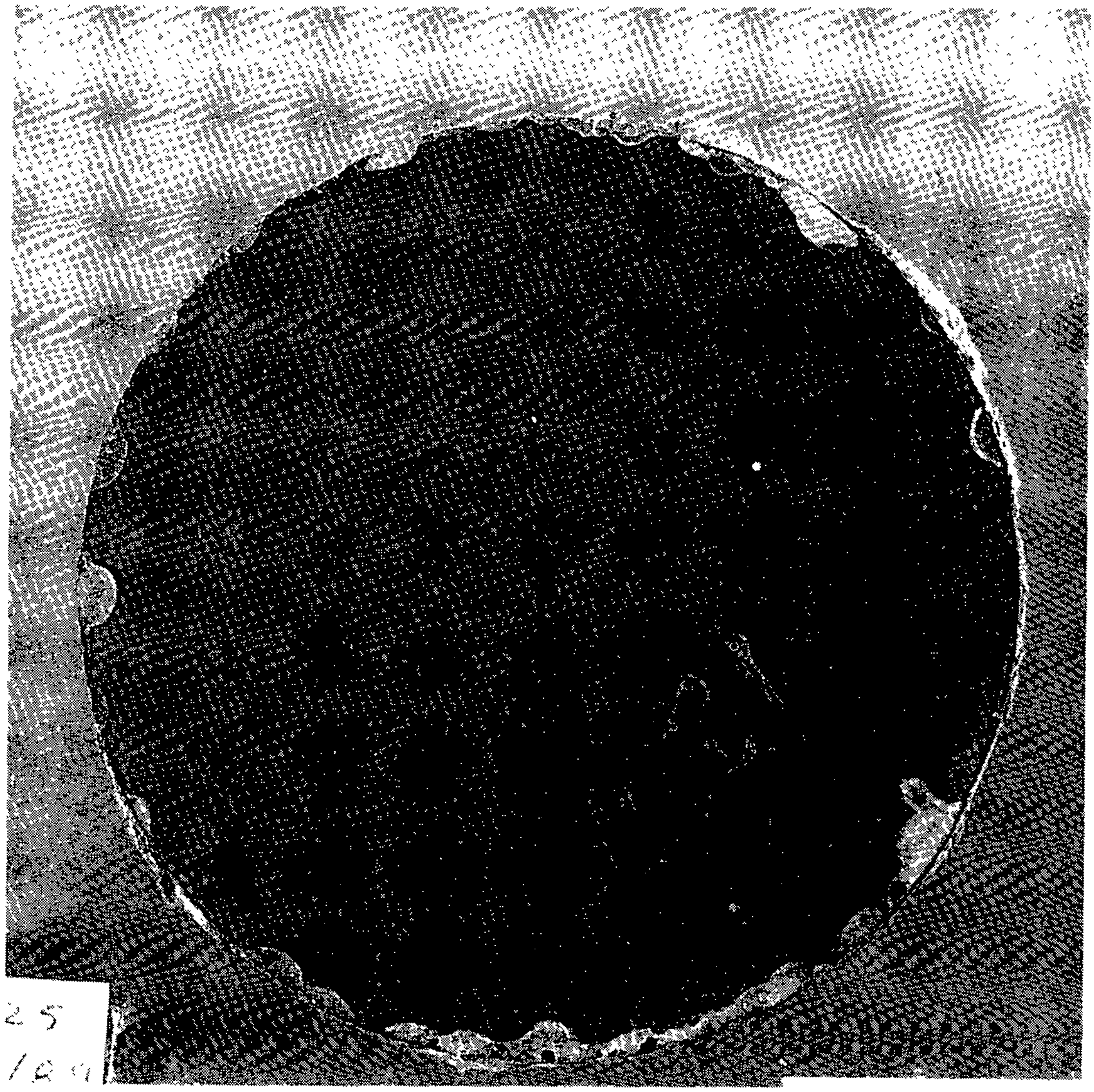

Figure 50 Post Test 5-F12-161, 2700 degrees F partially bonded, front view

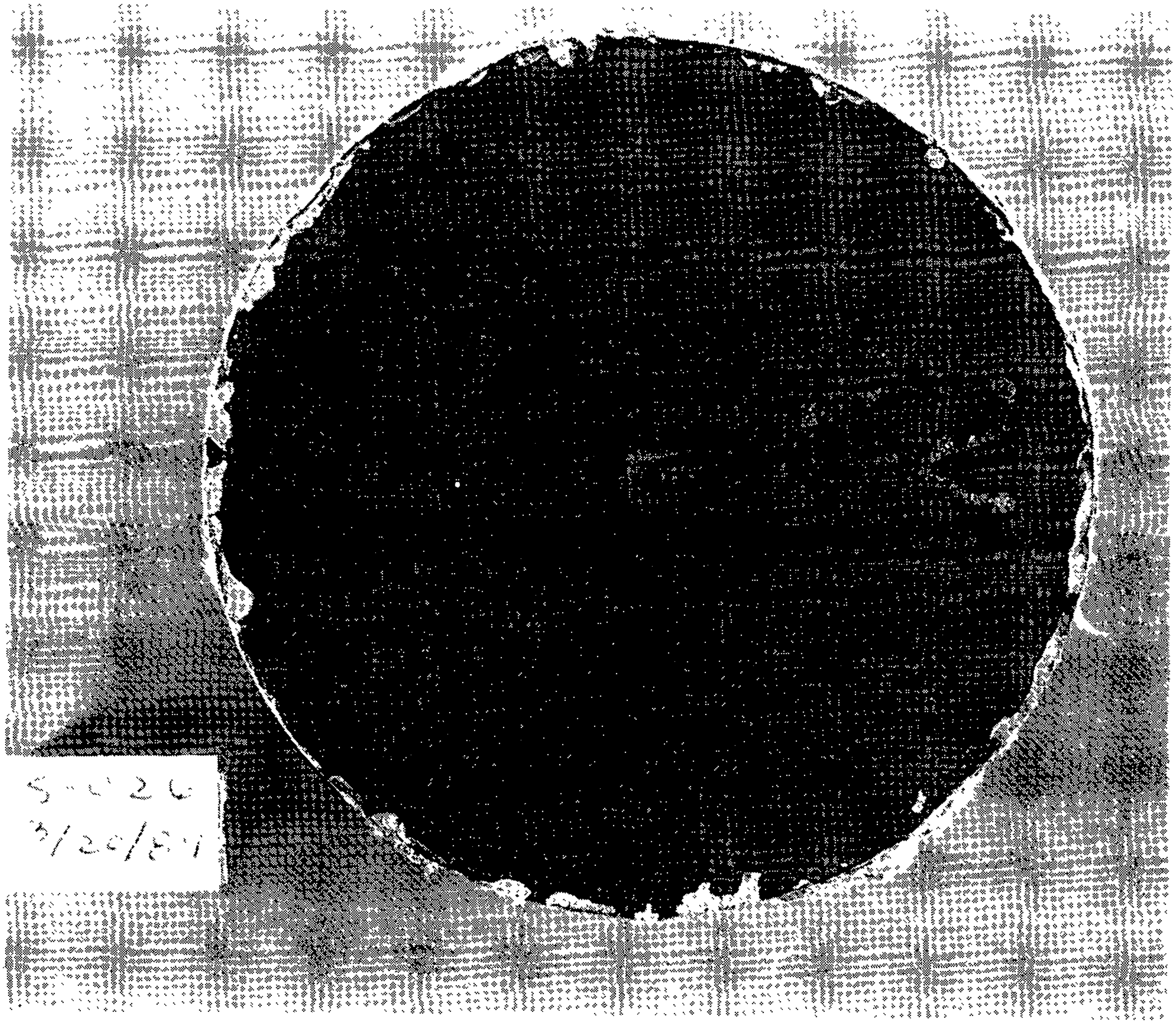

Figure 51 Post Test 7-L22-163, 2900 degrees F partially bonded, front view

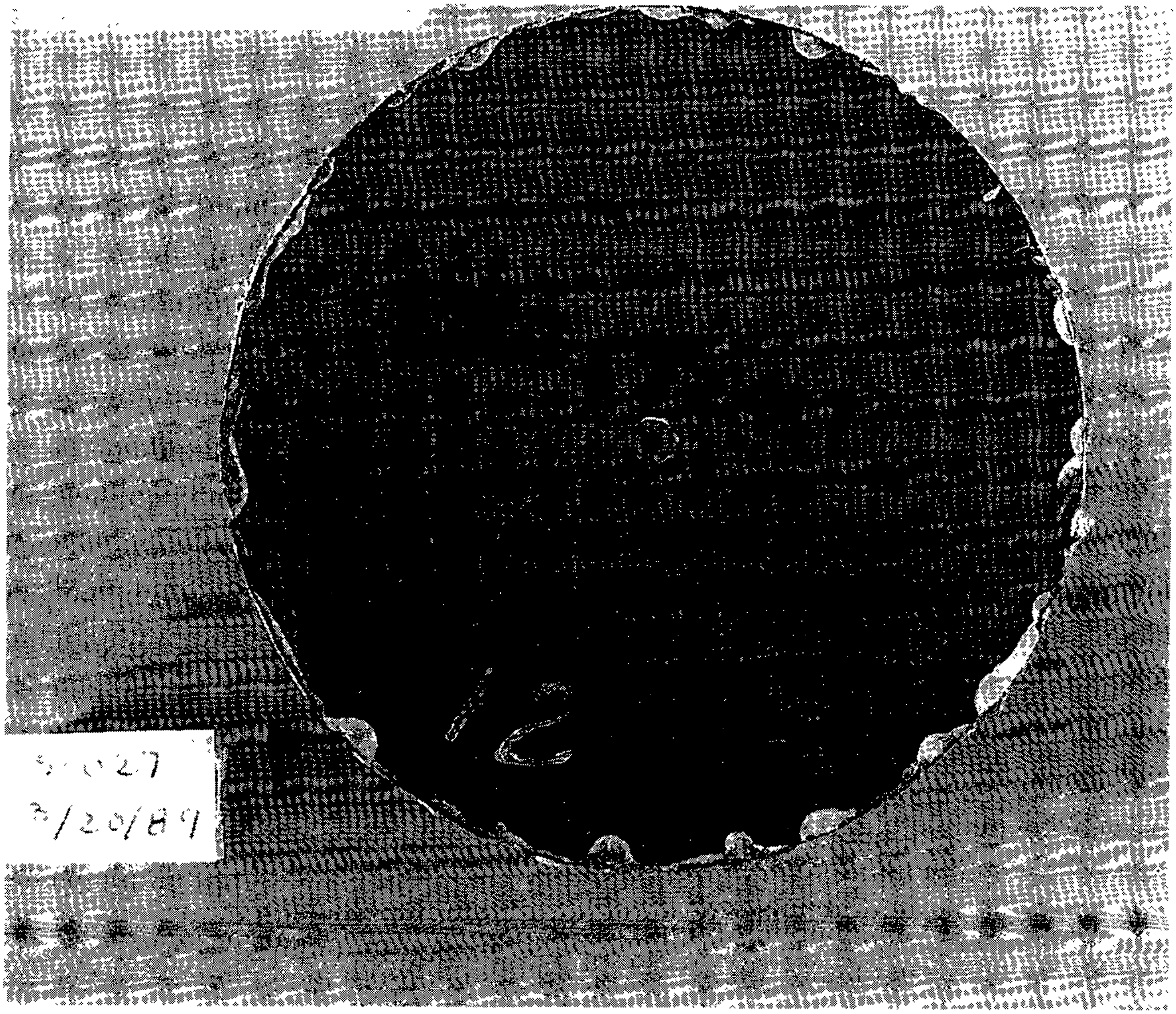

Figure 52 Post Test 8-F12-164, 2800 degrees F
partially bonded, front view
mishandled when removed from arc-jet

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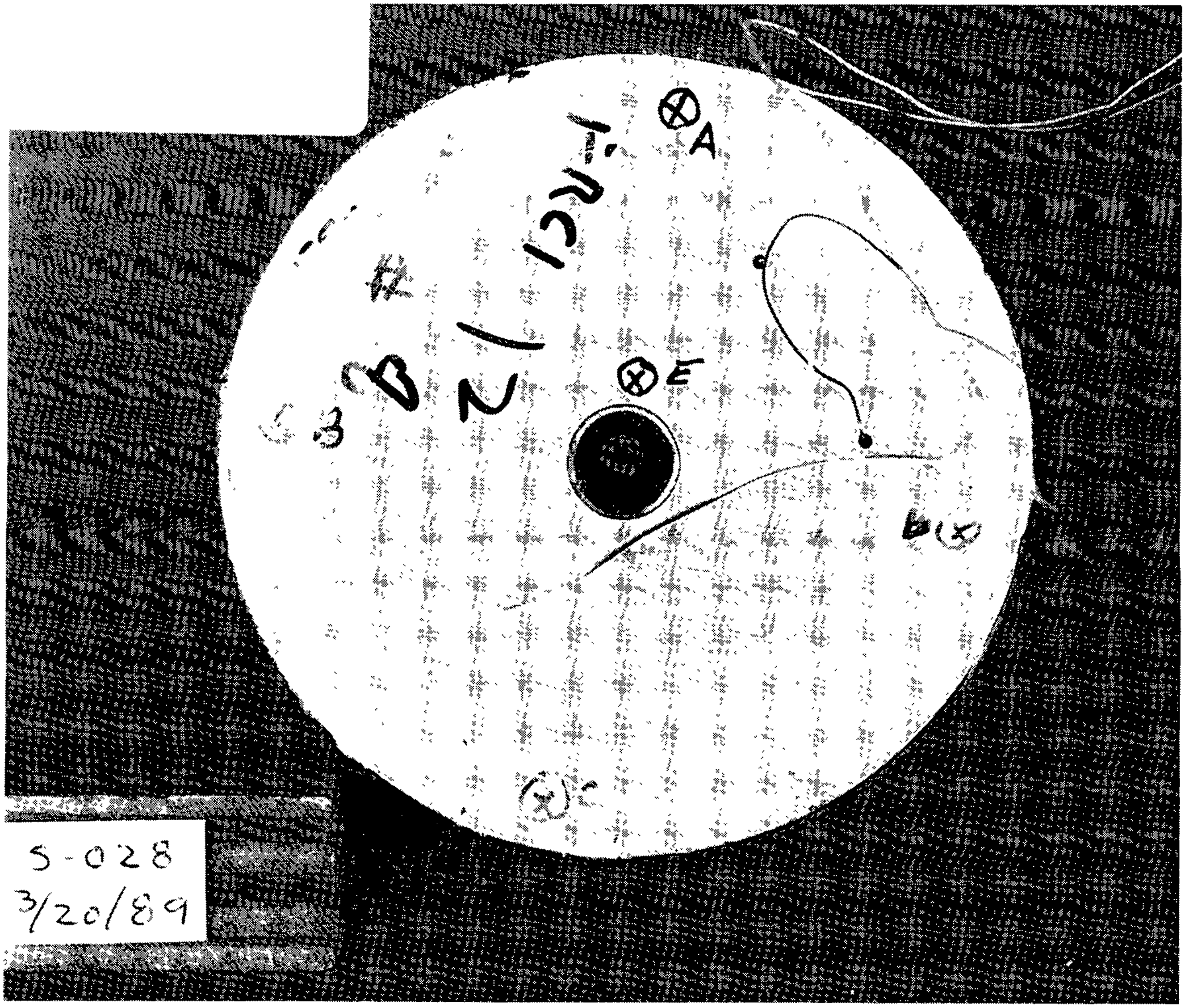


Figure 53 Post Test 8-F12-164, 2800 degrees F partially bonded, rear view

BLACK AND WHITE PHOTOGRAPH

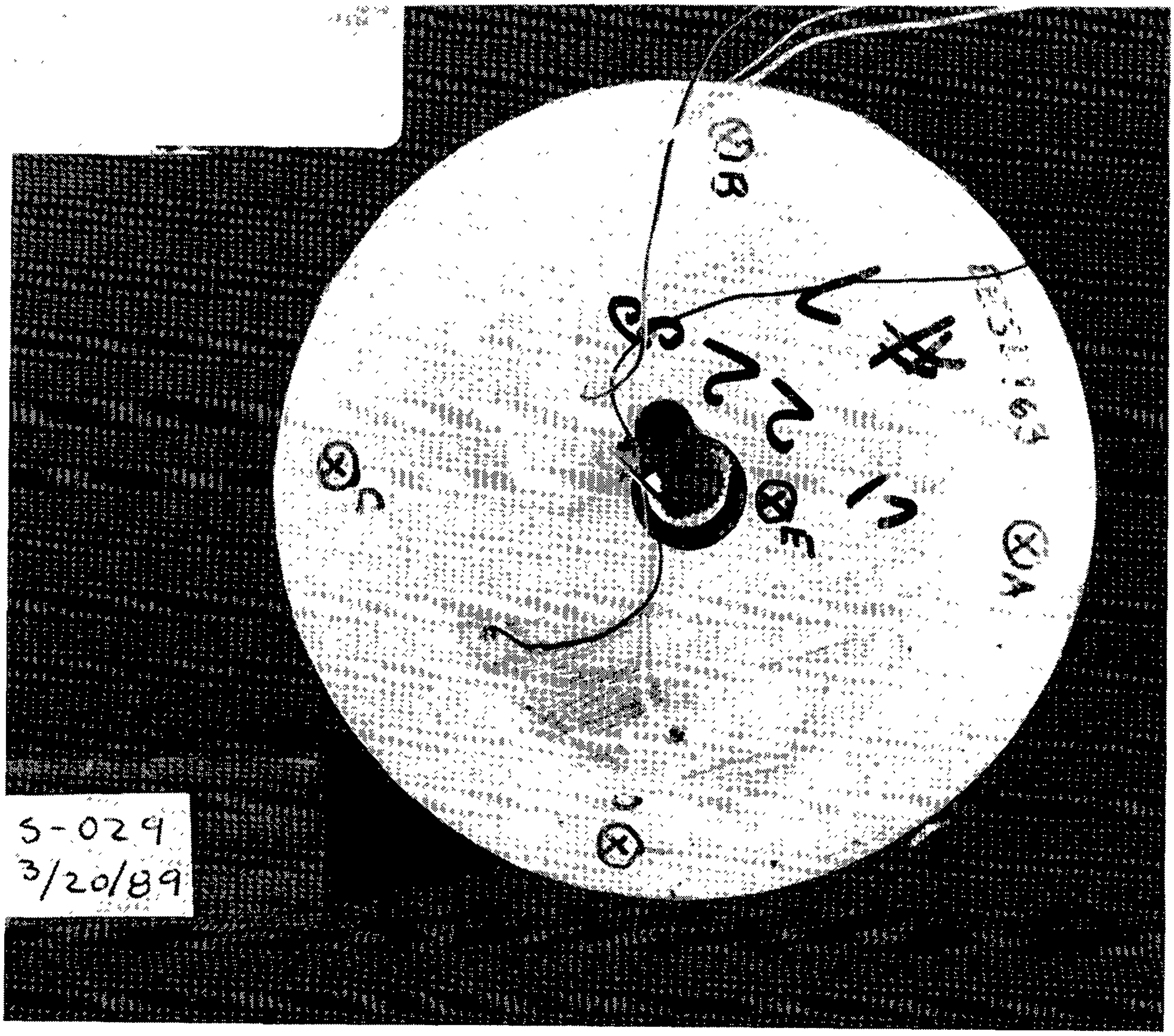


Figure 54 Post Test 7-L22-163, 2900 degrees F partially bonded, rear view

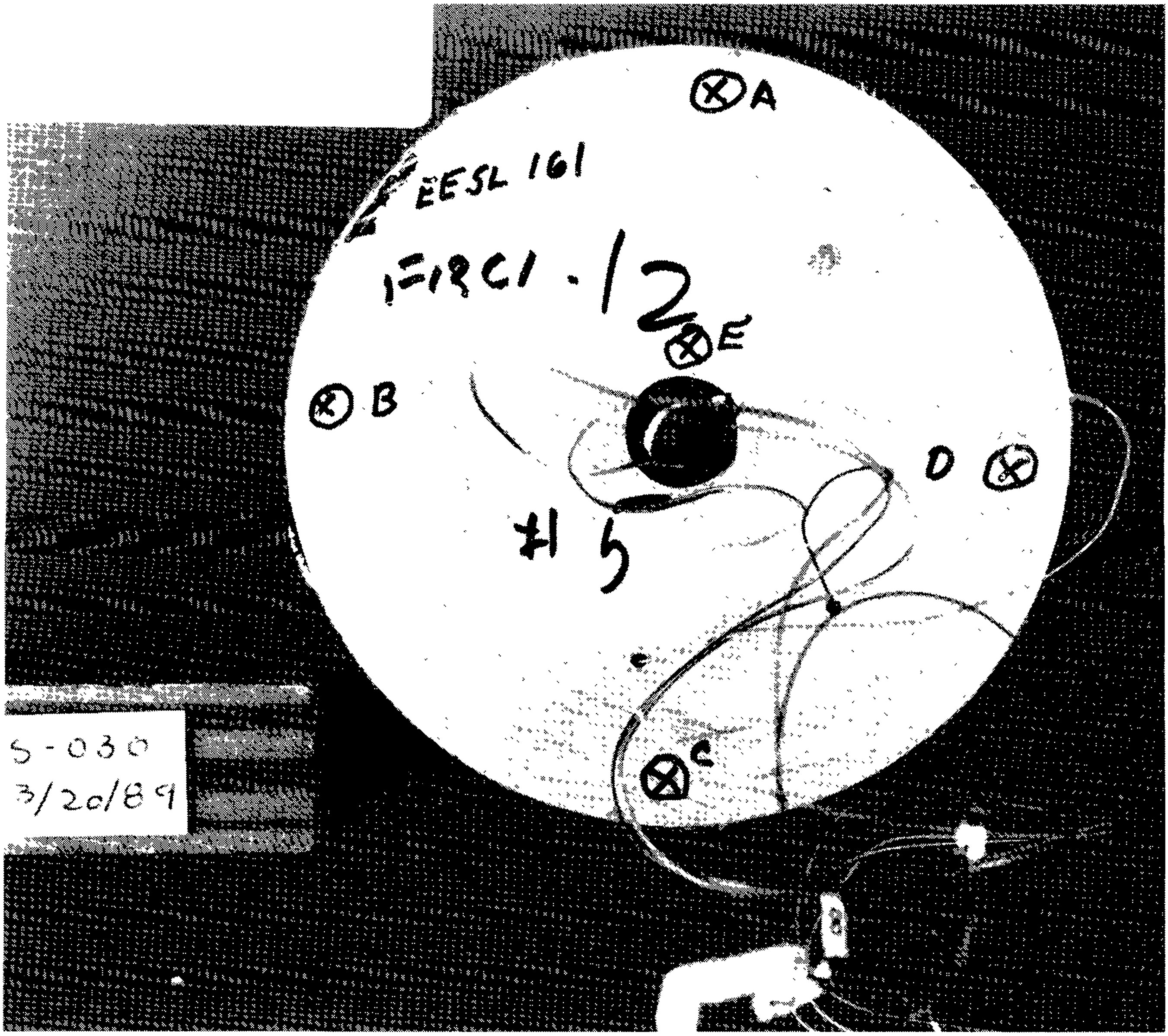


Figure 55 Post Test 5-F12-161, 2700 degrees F partially bonded, rear view

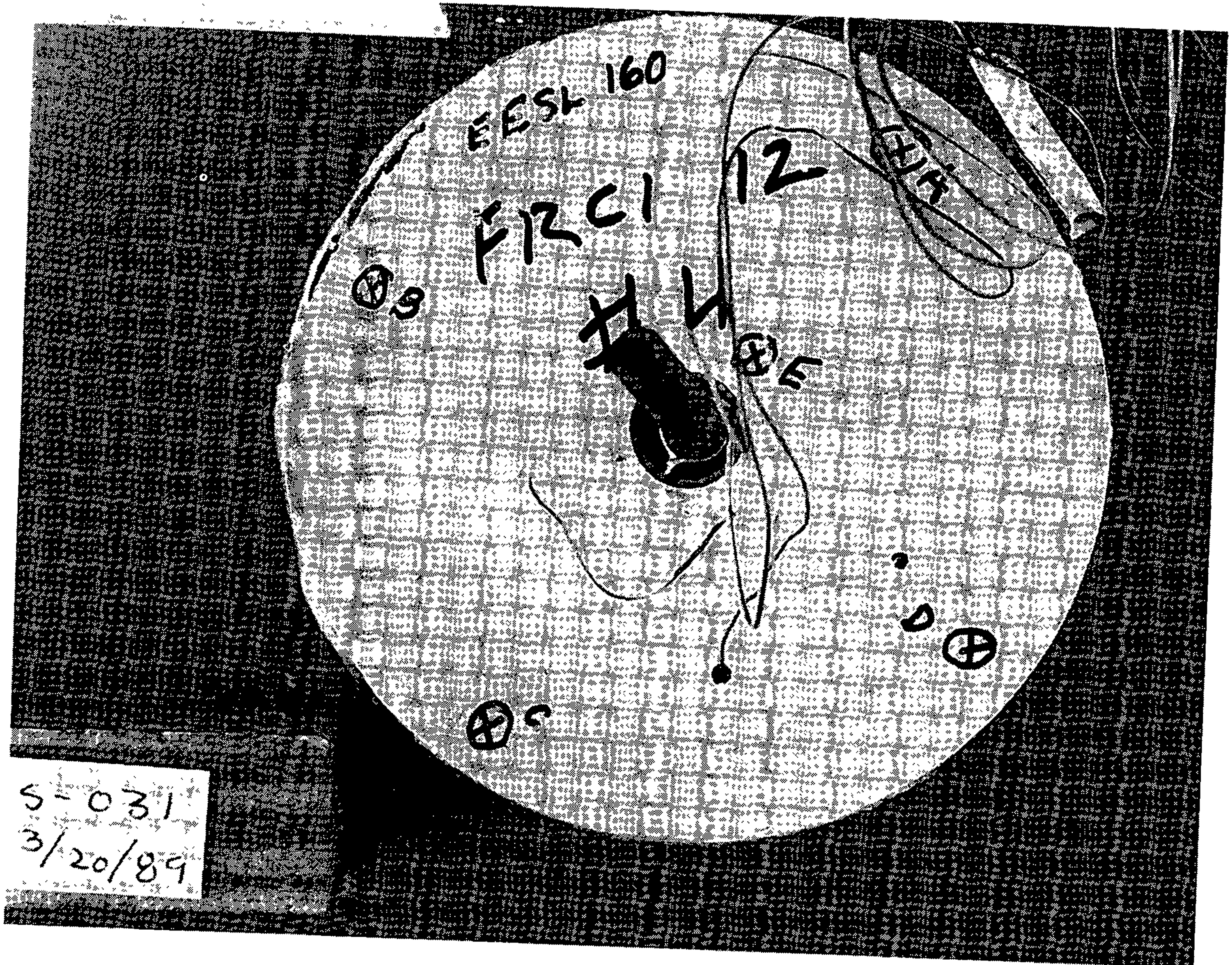


Figure 56 Post Test 4-F12FB-160, 2800 degrees F fully bonded, rear view

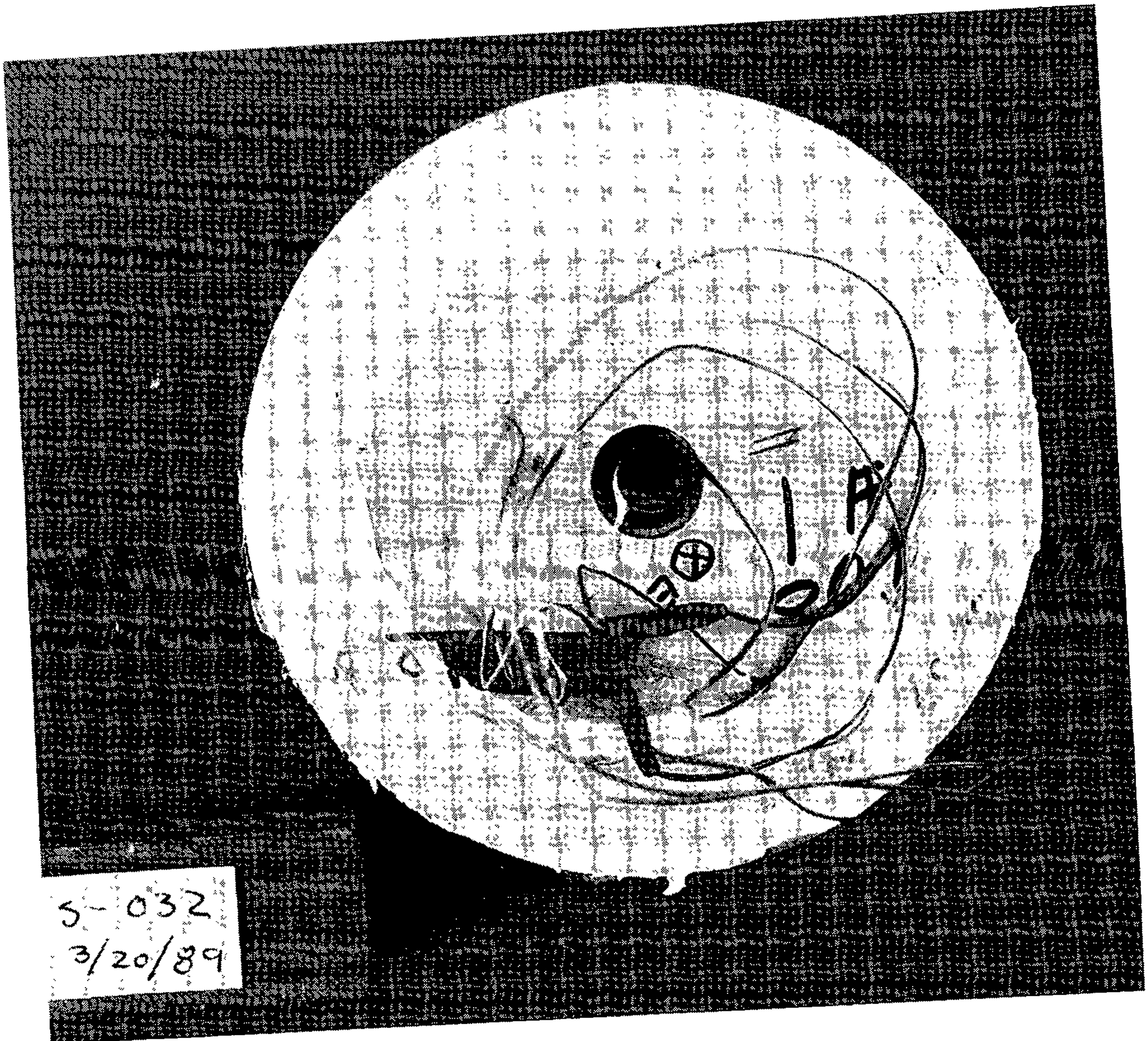


Figure 57 Post Test 1-L9FB-157, 2300 degrees F fully bonded, rear view

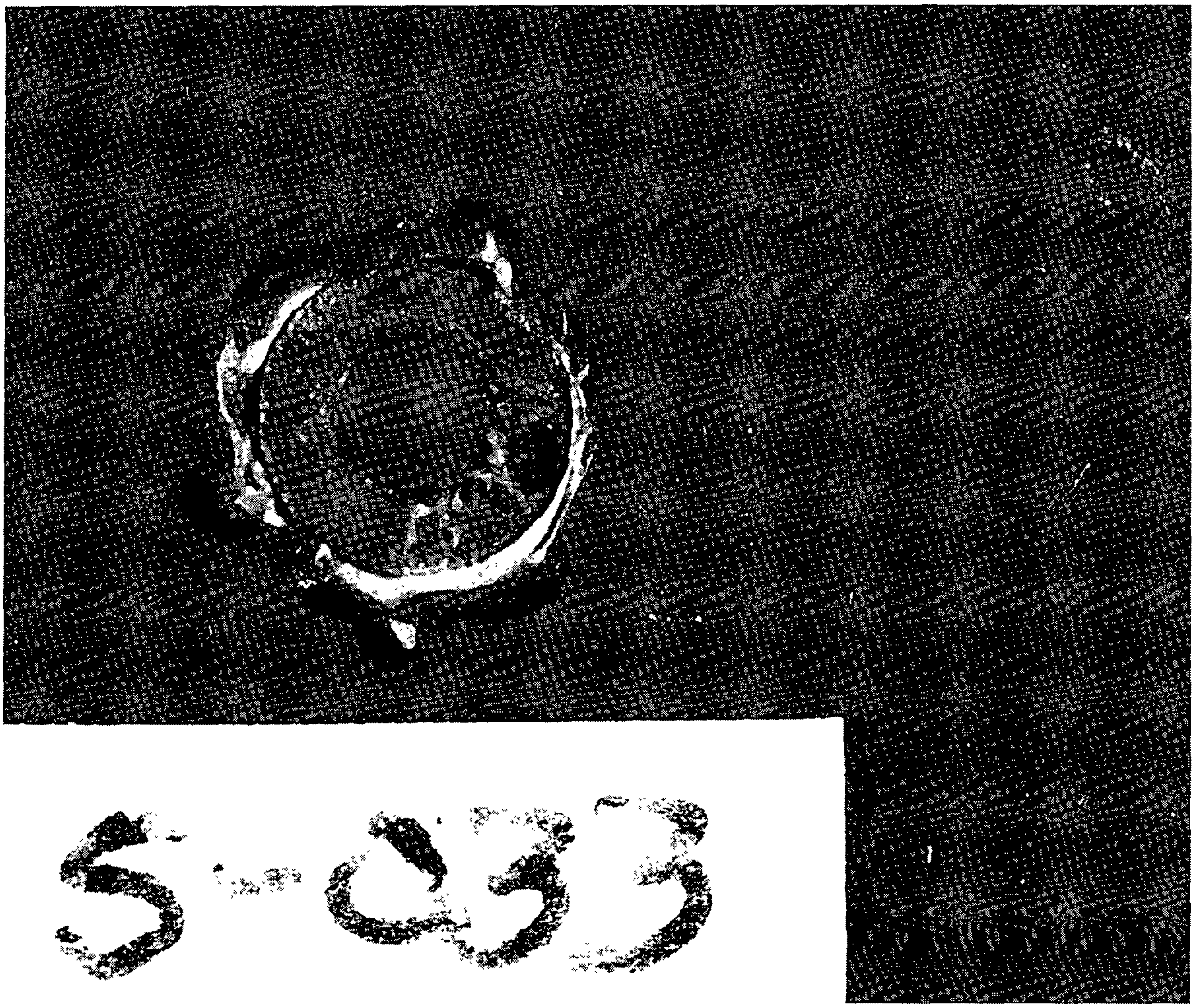


Figure 58 Post Test 8-F12-164, 2800 degrees F, Close-up..
partially bonded, front view
mishandled, was not damaged when
initially inspected in the arc chamber

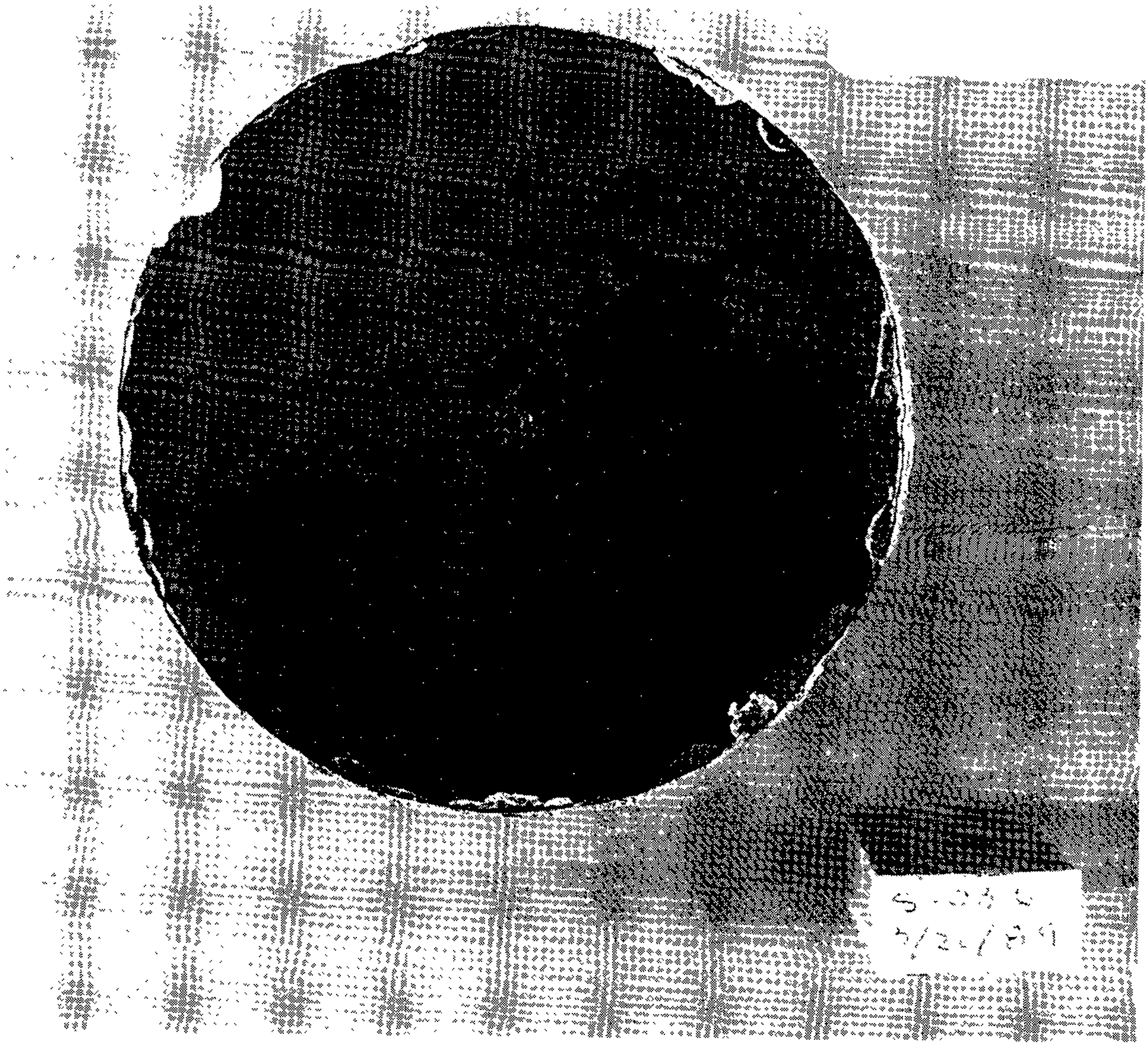


Figure 59 Post Test 2-L22FB-158, 2900 degrees F fully bonded, front view

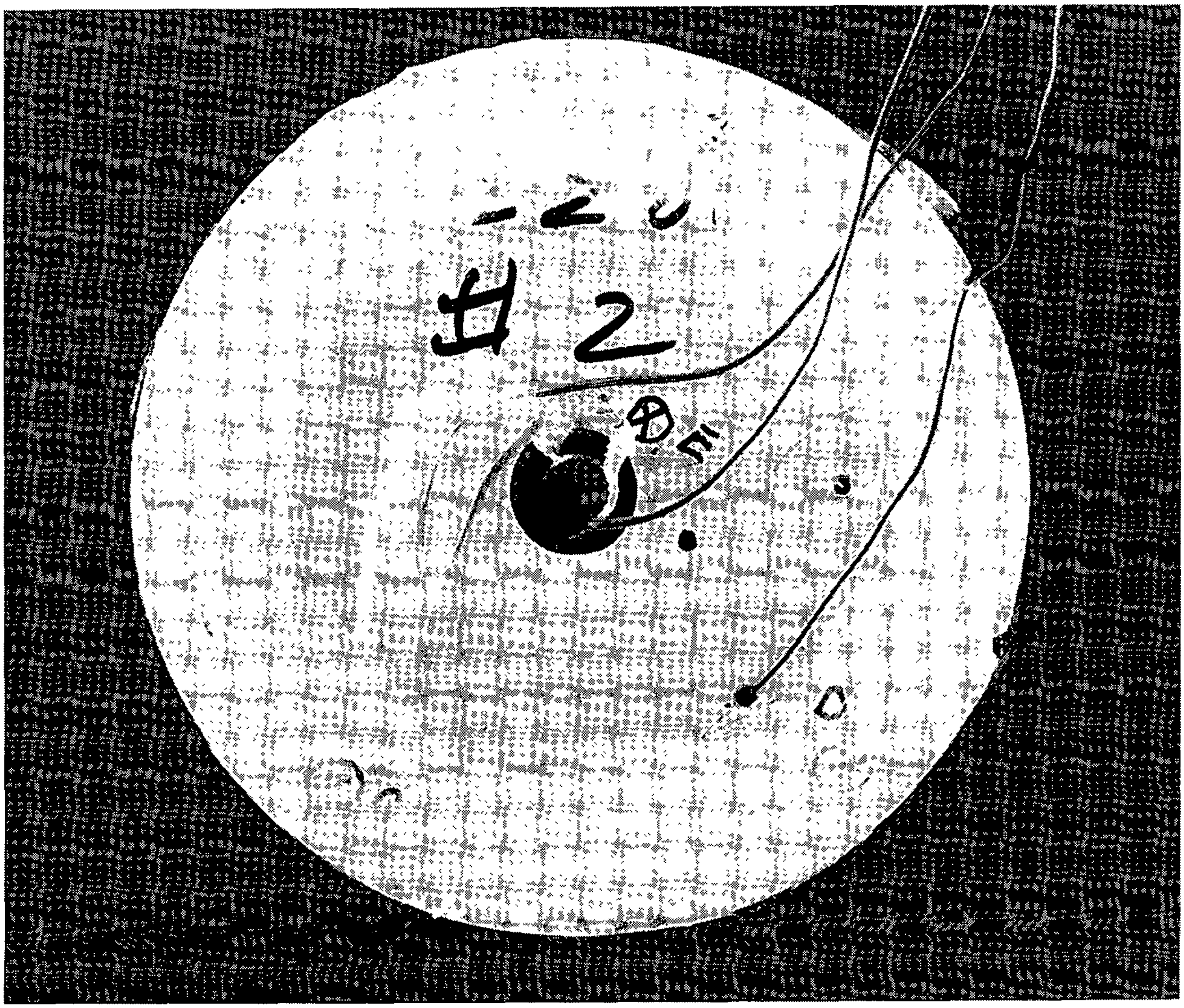
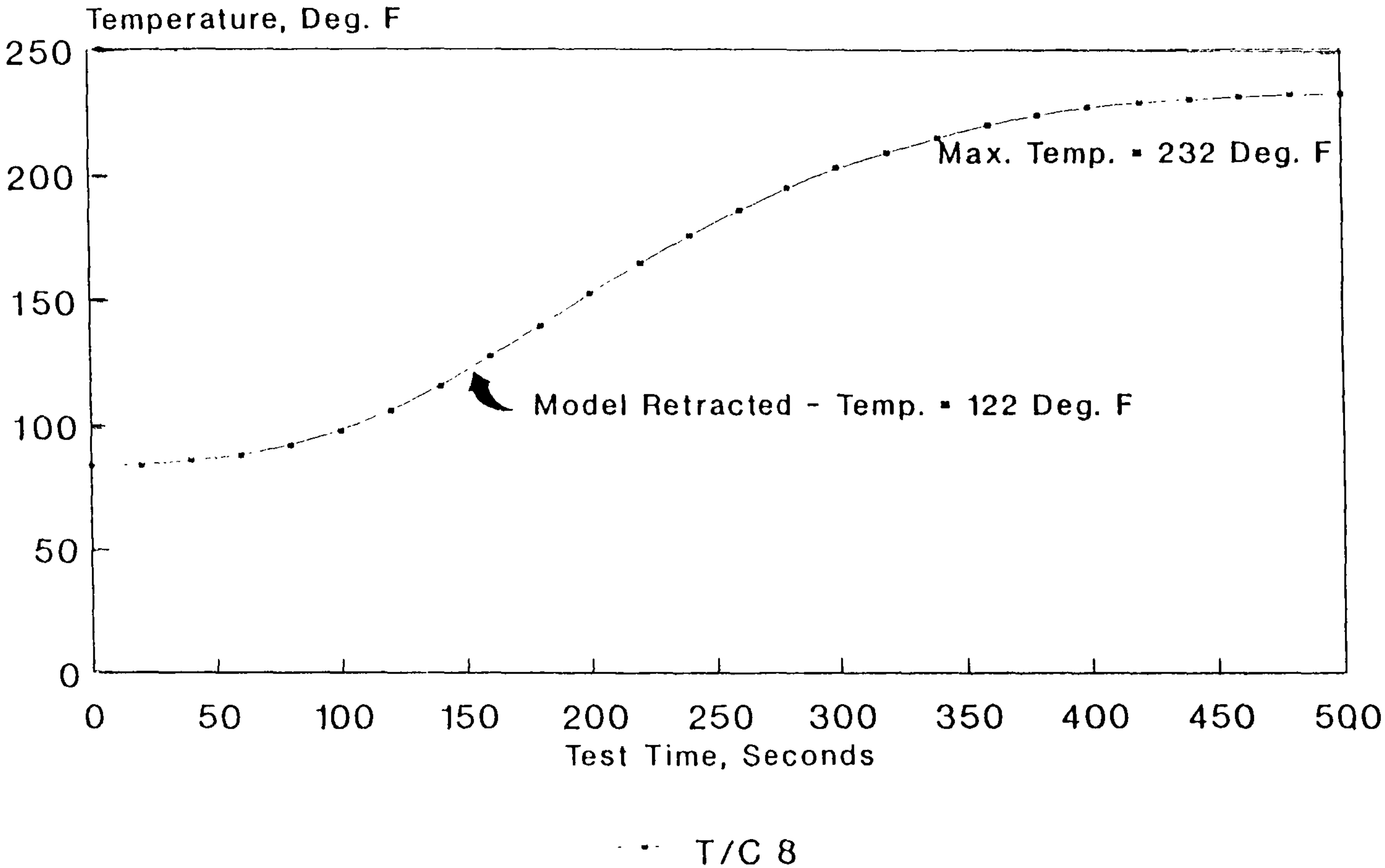


Figure 60 Post Test 2-L22FB-158, 2900 degrees F fully bonded, rear view

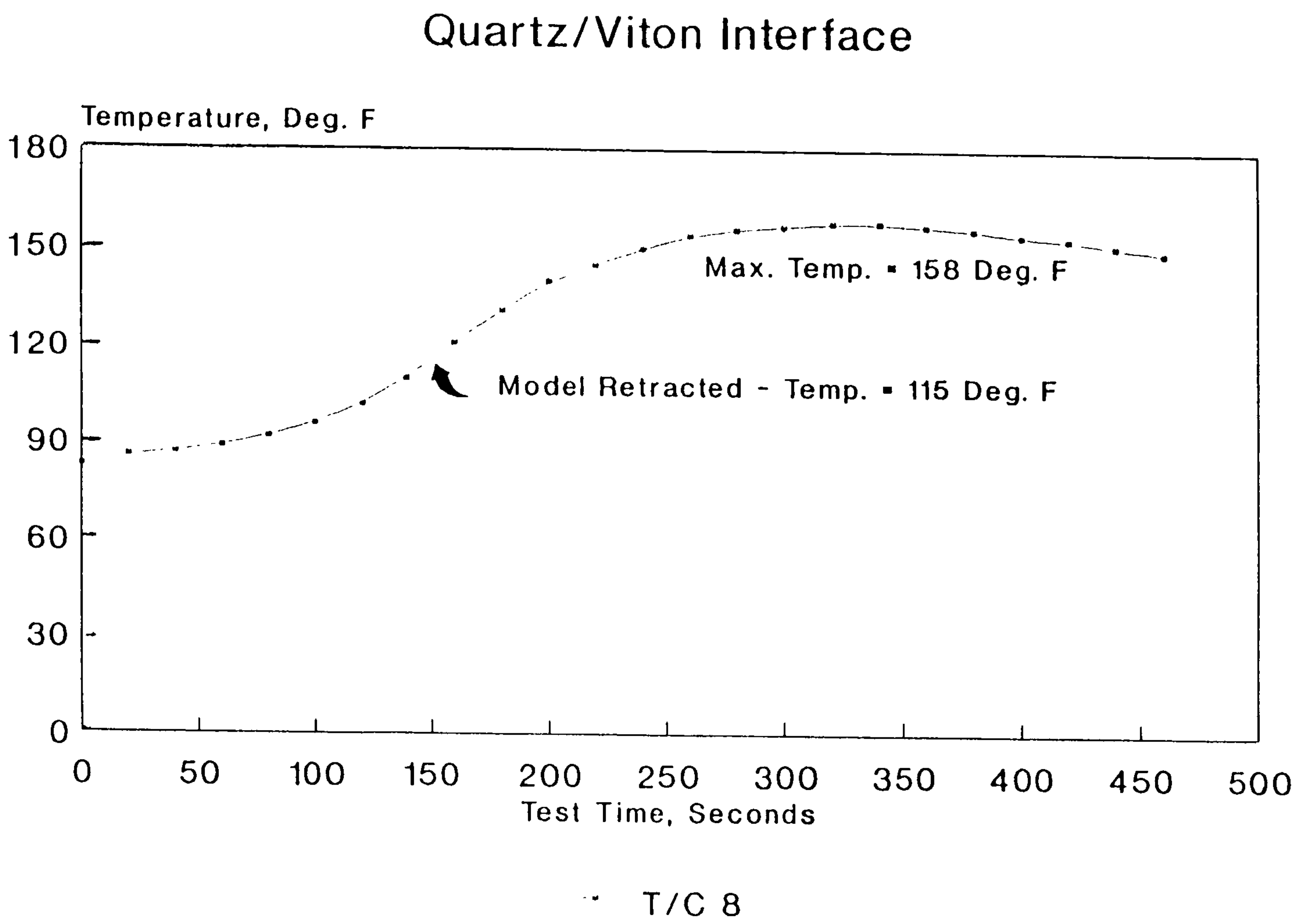
Quartz/Viton Interface



Temperature Response to
2300 Deg. Surface Temp.
Run 913, 1-L9FB-157

L.P. MURRAY/LESC

Figure 61

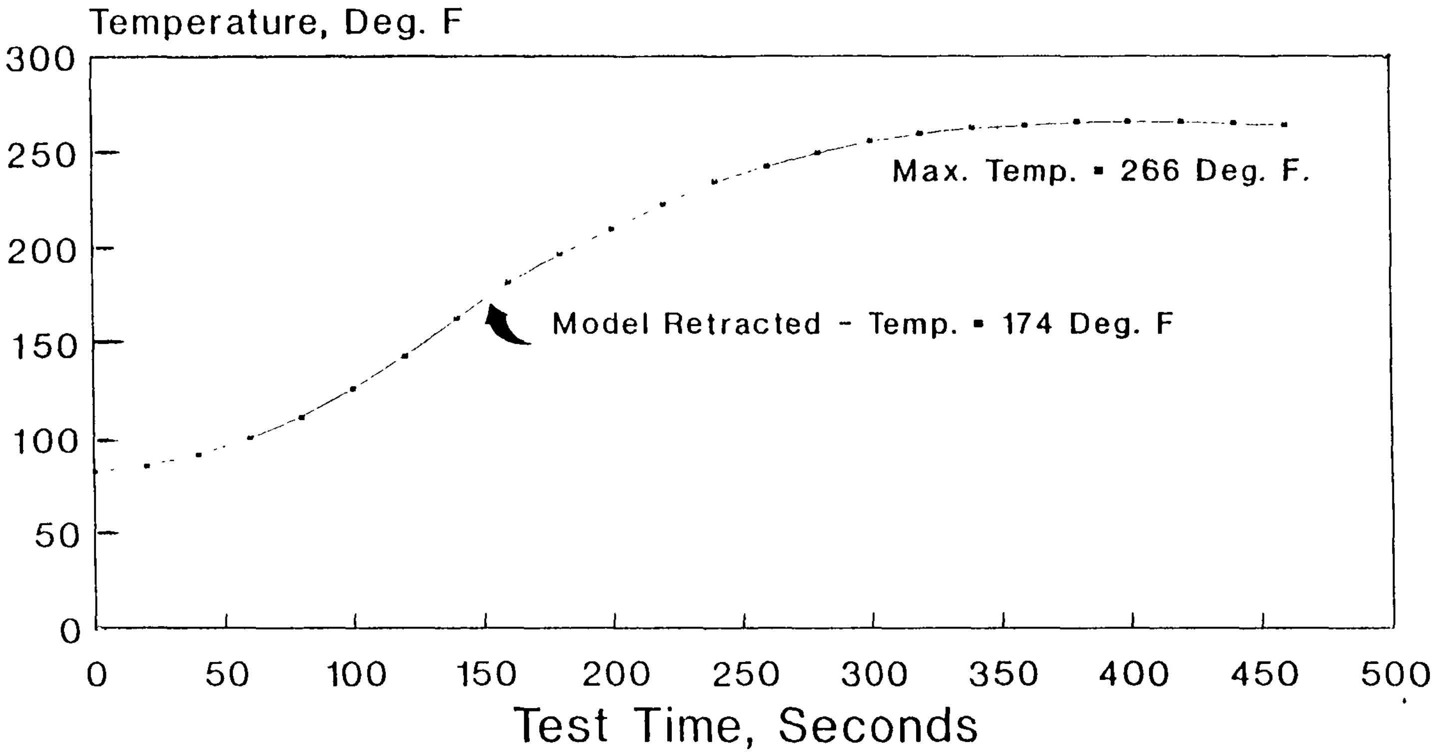


Temperature Response to
2300 Deg. Surface Temp.
Run 906, 6-L9-162

Figure 62

L.P. MURRAY/LESC

Quartz/Viton Interface



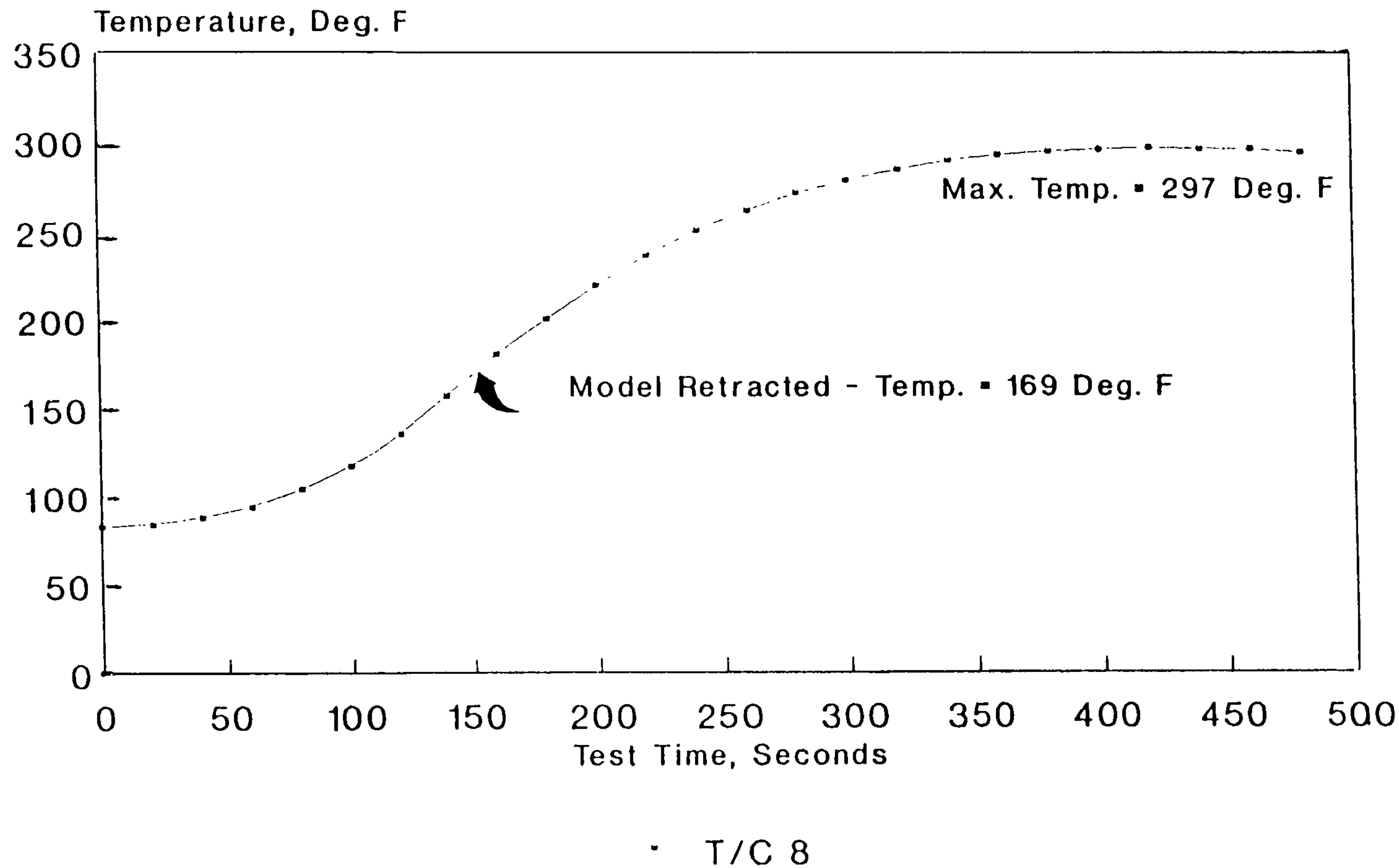
T/C 8

Temperature Response to
2700 Deg. Surface Temp.
Run 907, 3-F12FB-159

L.P. MURRAY/LESC

Figure 63

Quartz/Viton Interface

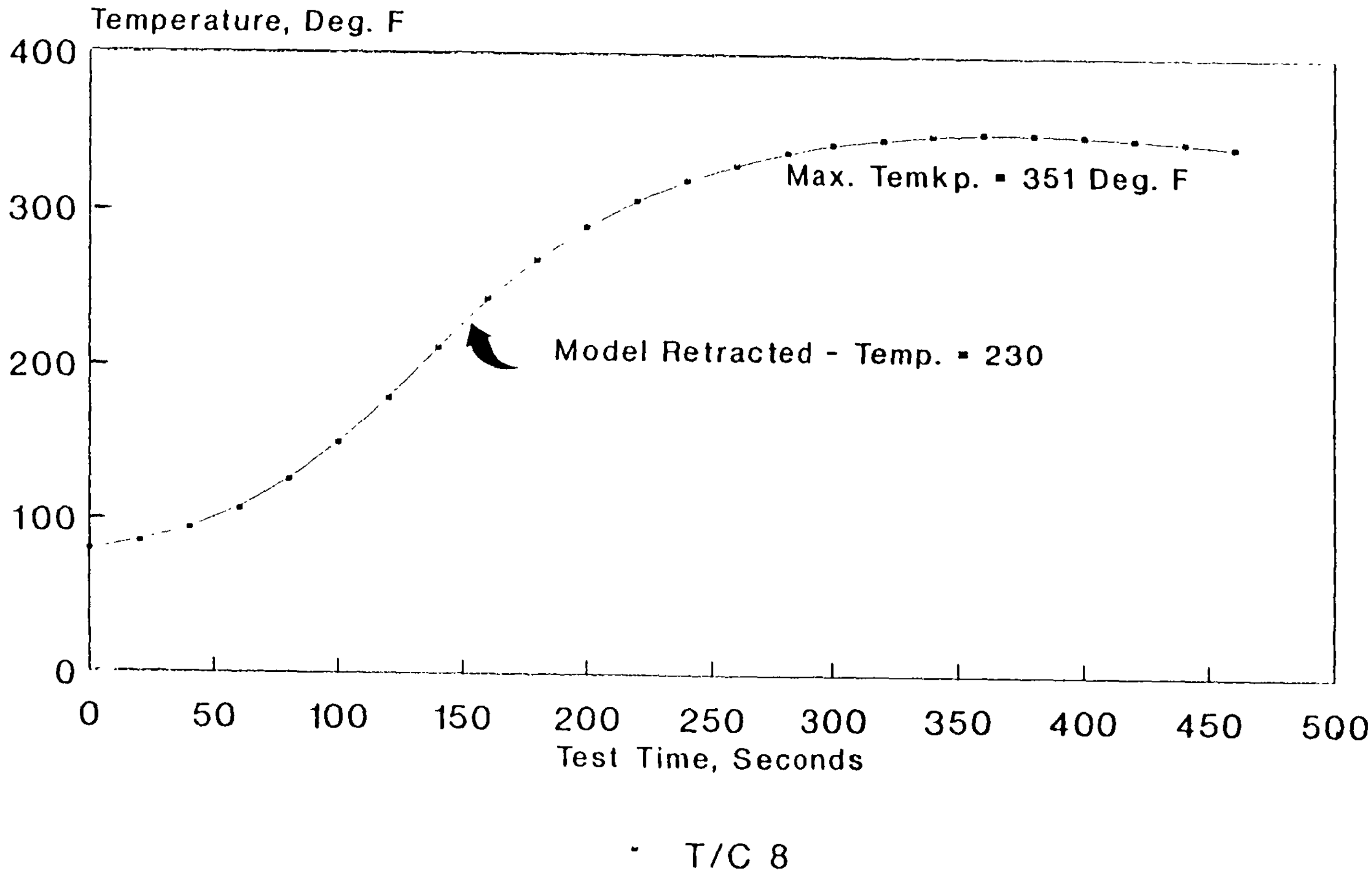


Temperature Response to
2700 Deg. Surface Temp.
Run 908, 5-F12-161

L.P. MURRAY/LESC

Figure 64

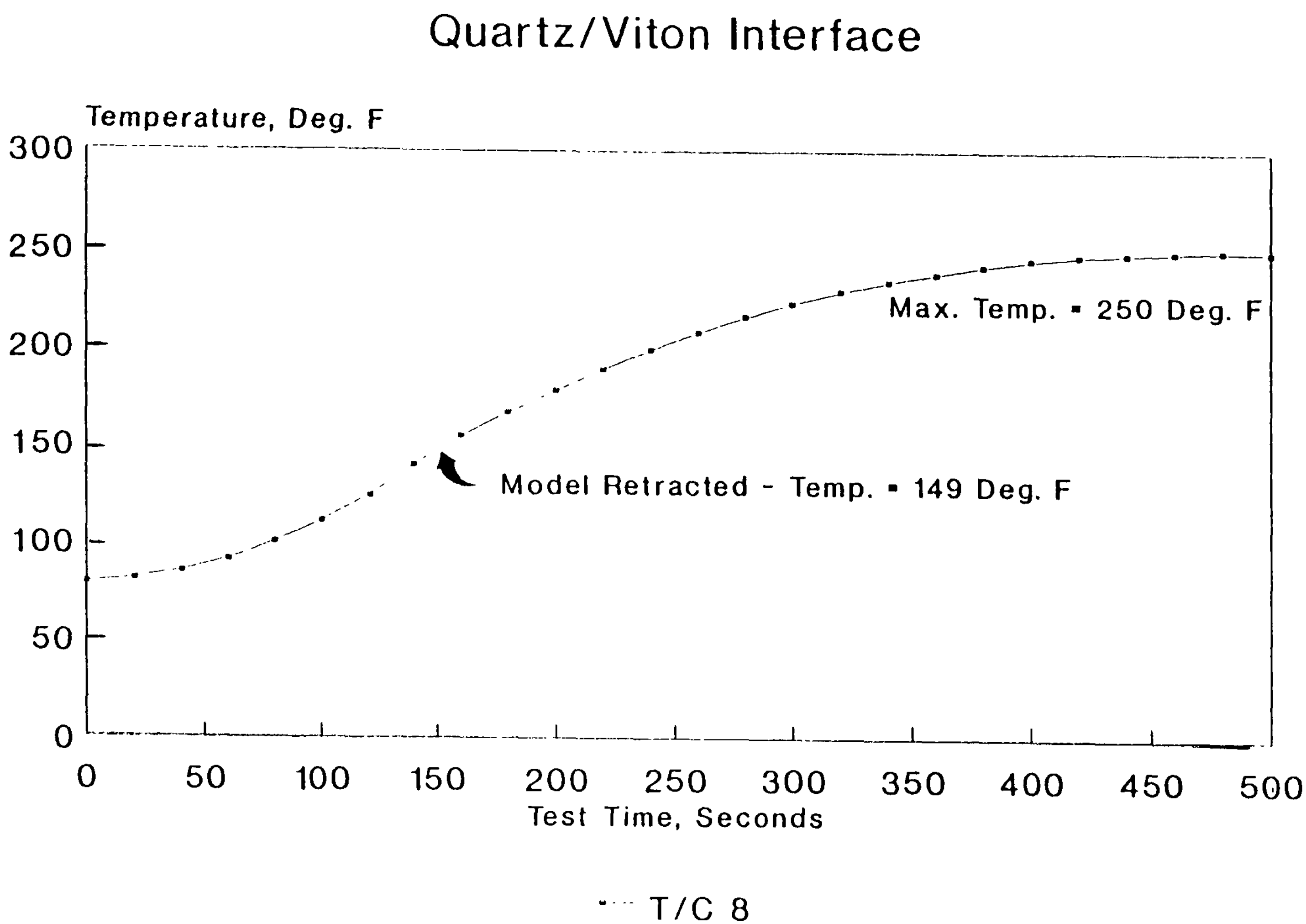
Quartz/Viton Interface



Temperature Response to
2800 Deg. Surface Temp.
Run 909, 4-F12FB-160

Figure 65

L.P. MURRAY/LESC

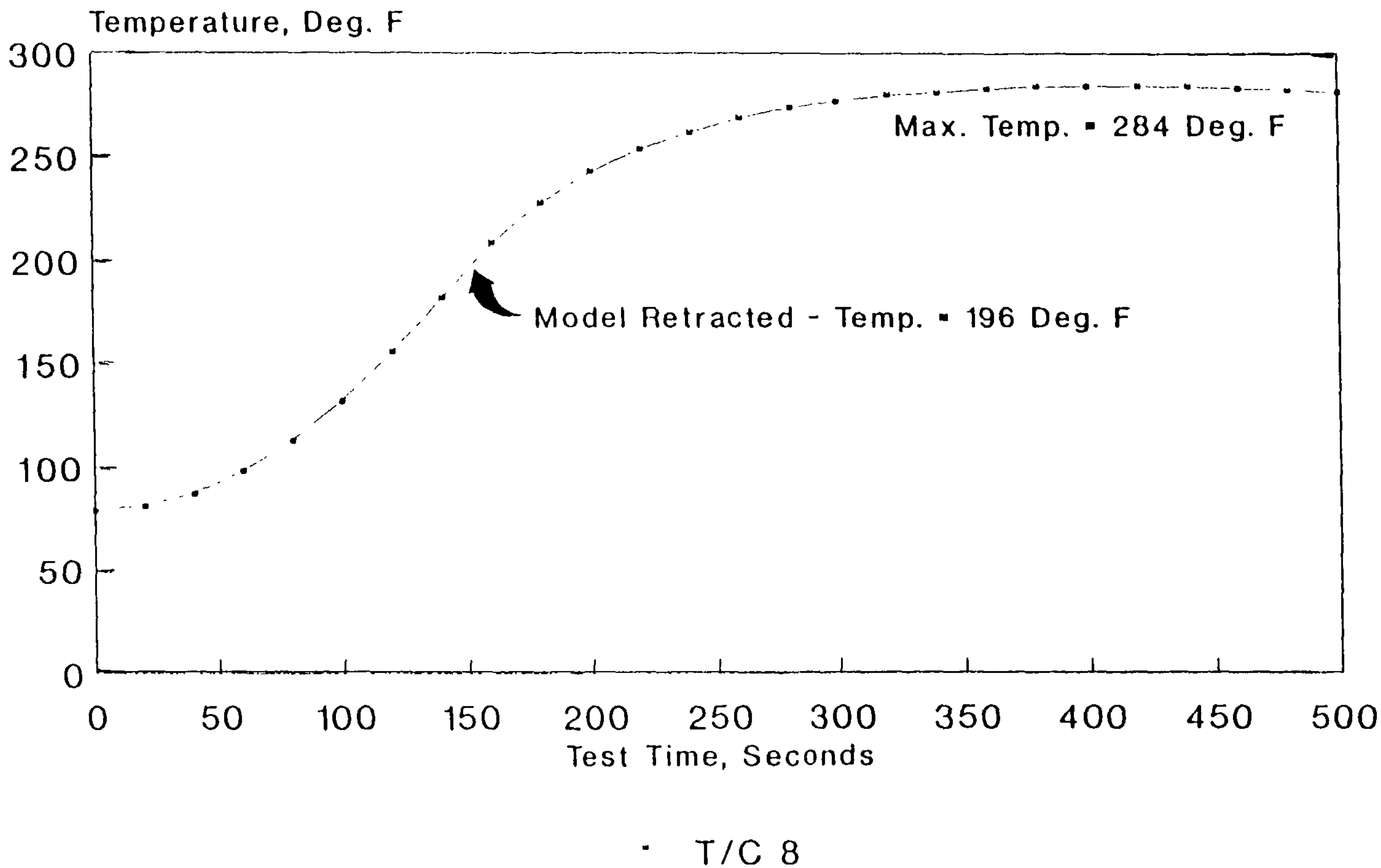


Temperature Response to
2800 Deg. Surface Temp.
Run 910, 8-F12-164

L.P. MURRAY/LESC

Figure 66

Quartz/Viton Interface

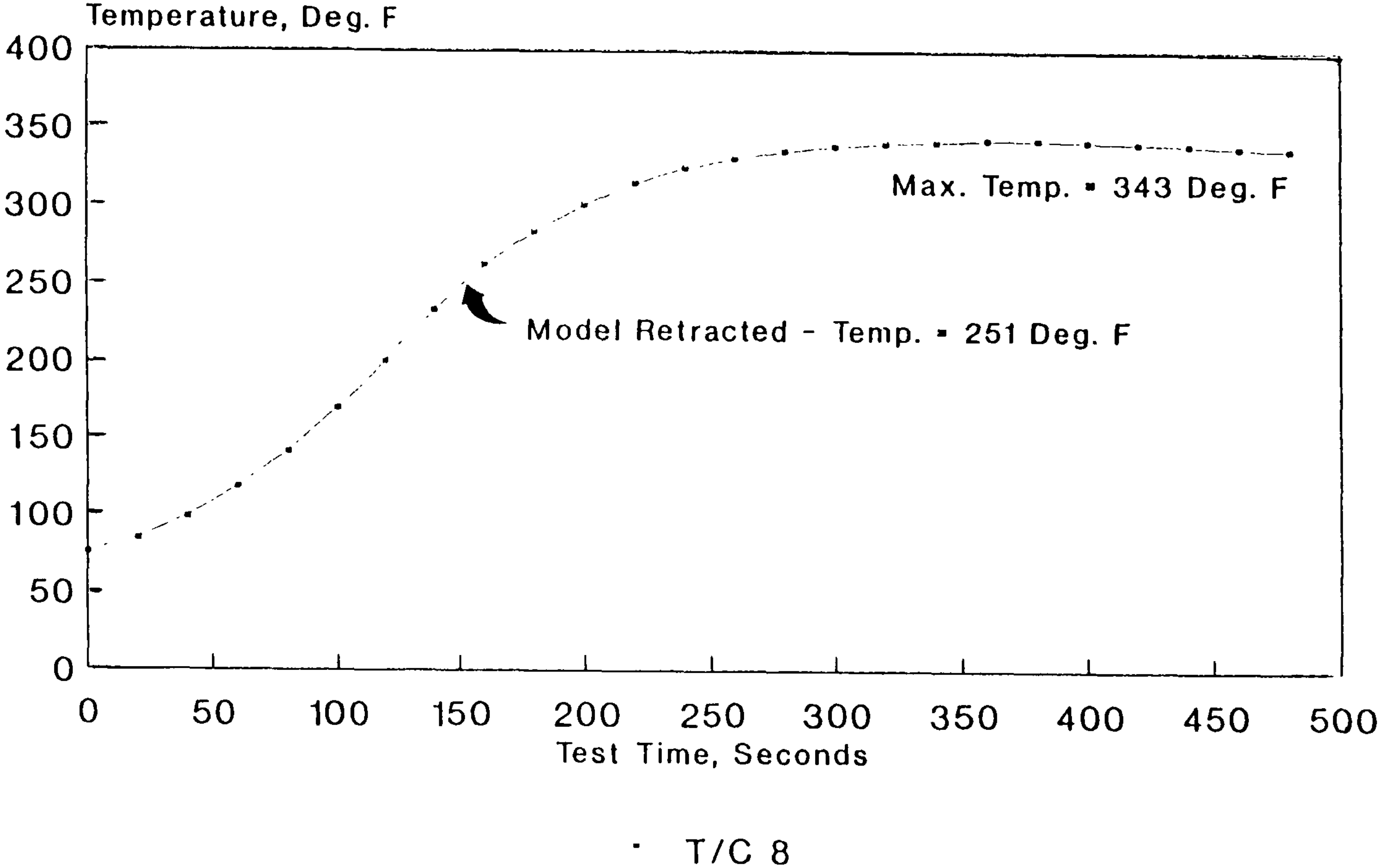


Temperature Response to
2900 Deg. Surface Temp.
Run 911, 7-L22-163

Figure 67

L.P. MURRAY/LESC

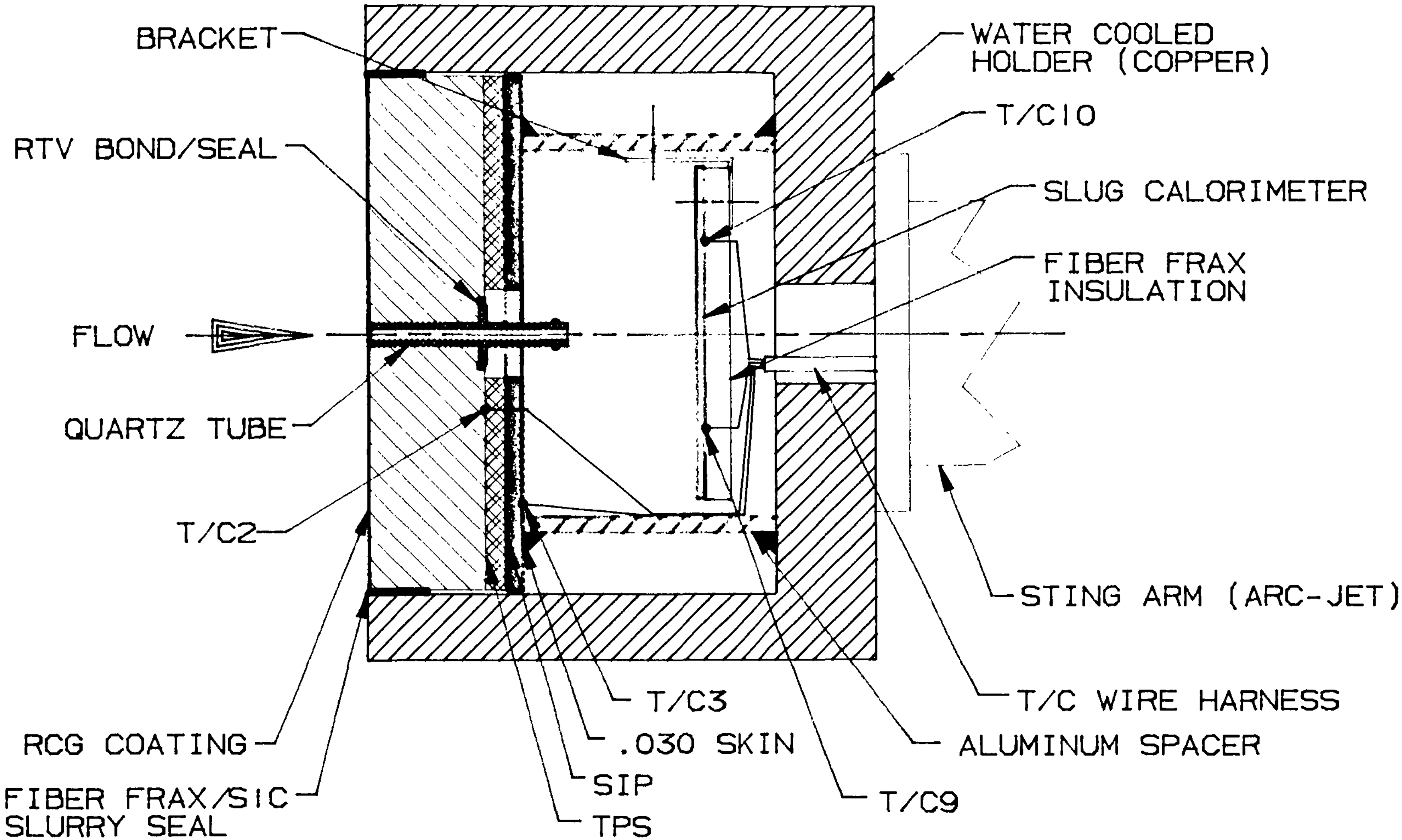
Quartz/Viton Interface



Temperature Response to
2900 Deg. Surface Temp.
Run 912, 2-L22FB-158

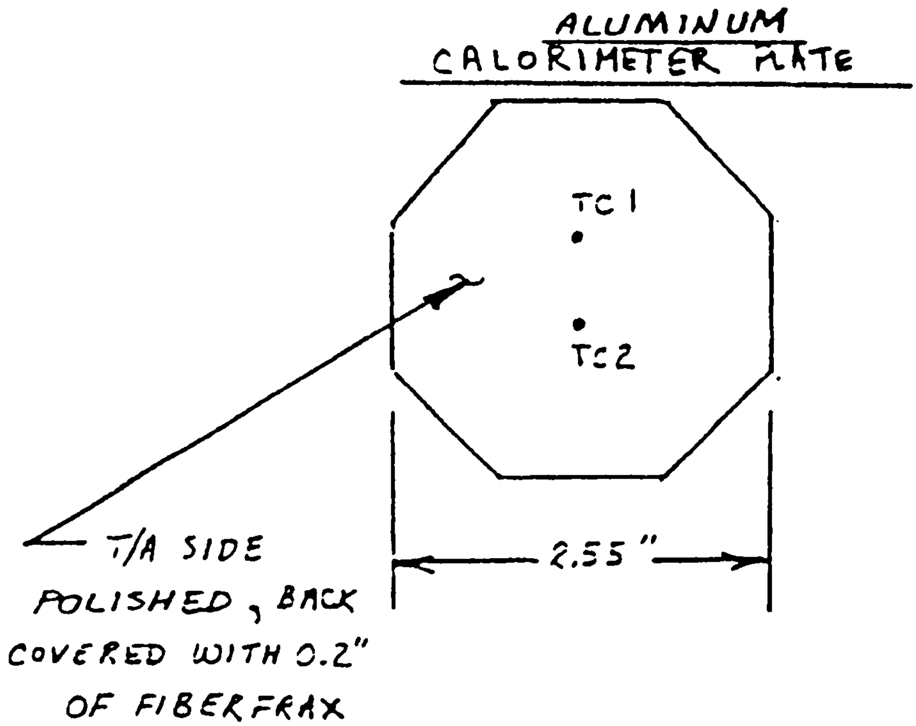
Figure 68

L.P. MURRAY/LESC



PD/ADS PRESSURE PORT TEST ARTICLE ARC-JET FACILITY INSTALLATION TUBE FAILURE TEST

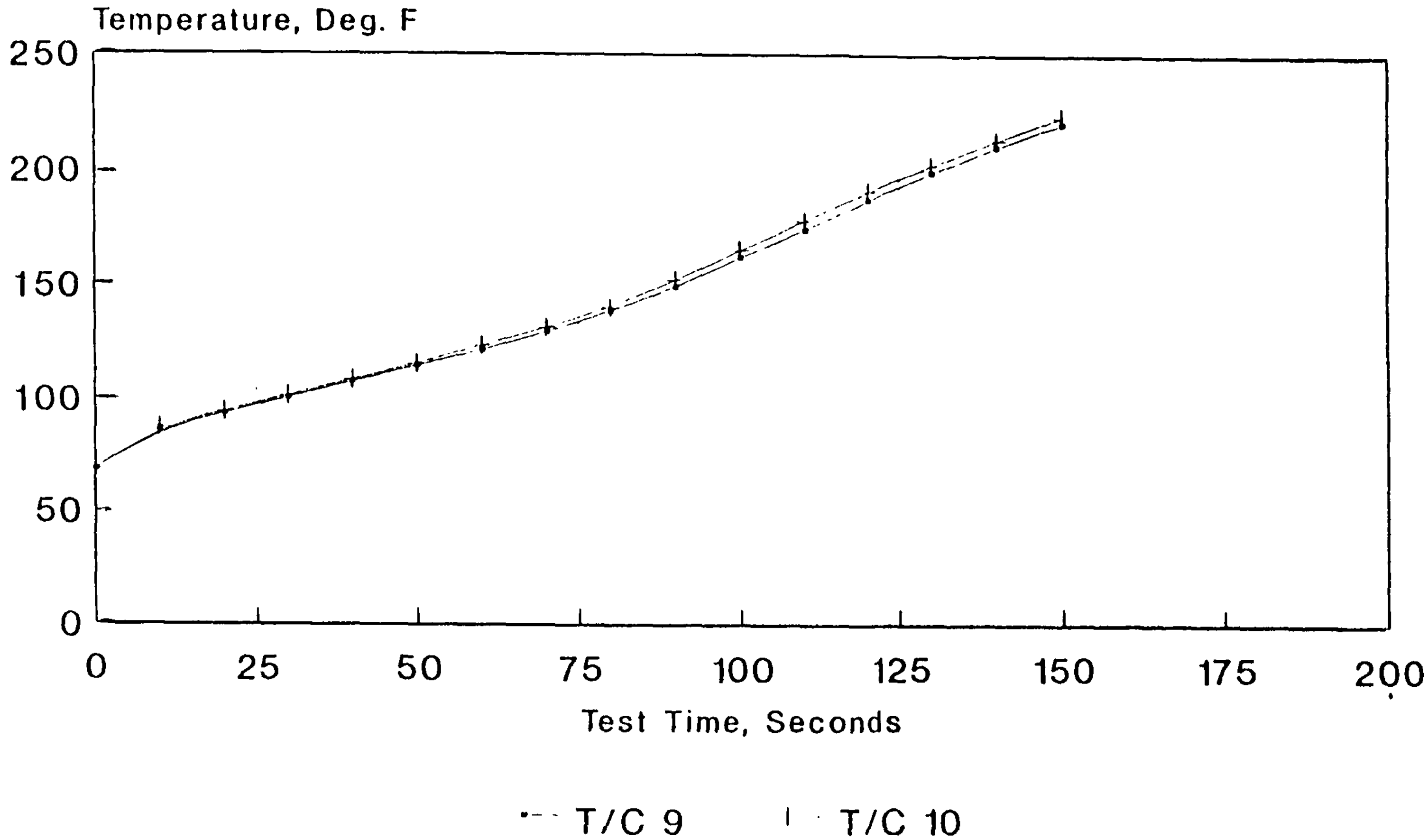
FIGURE 69



CONFIGURATION OF OPEN PORT FAILURE MODE TEST ARTICLE, SHOWING CALORIMETER PLATE.

Figure 70

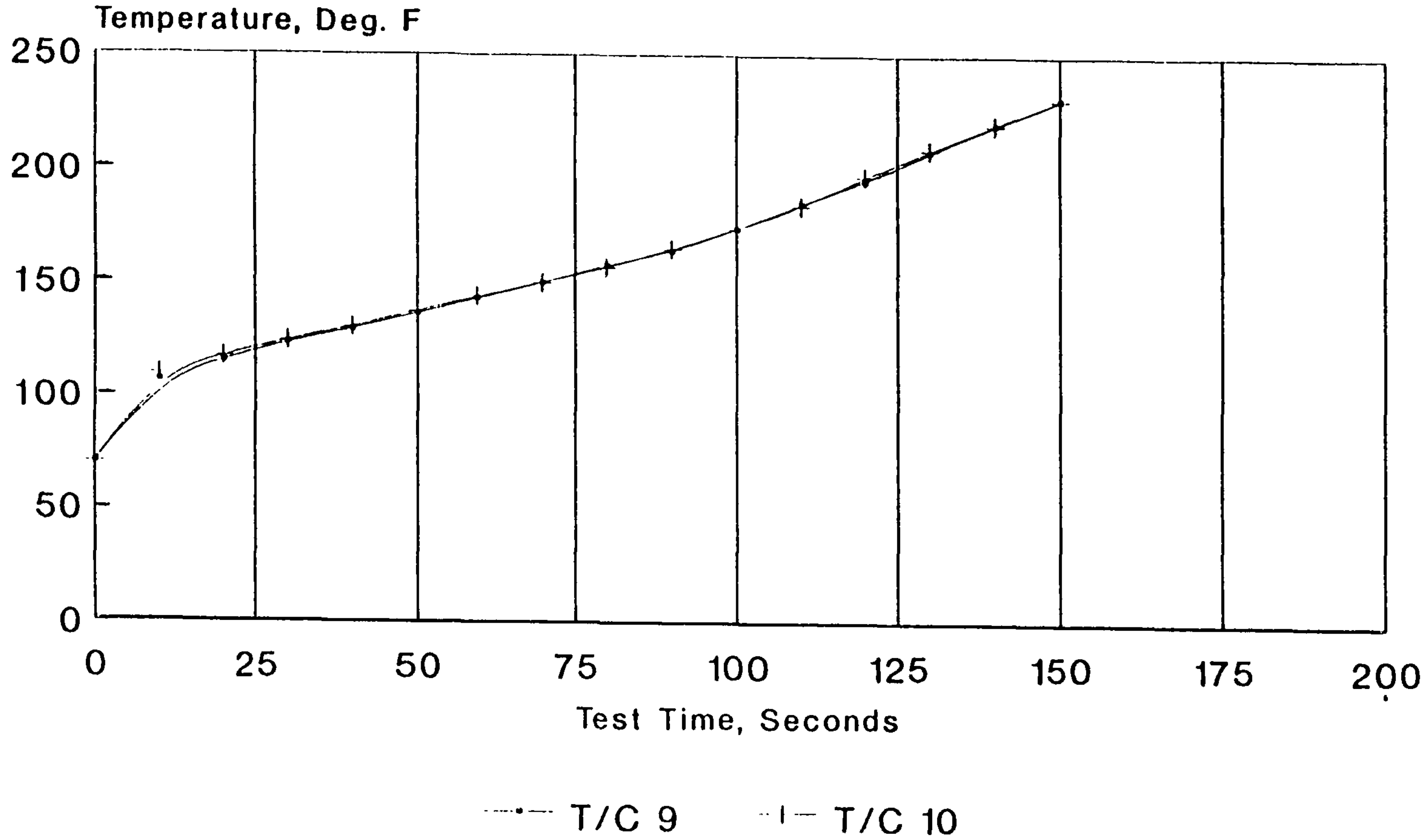
Temperature History Plots of Calorimeter Plates



Plots During Open Port
Failure Mode Tests
Run 914, 2-L22FB-158

Figure 71

Temperature History Plots of Calorimeter Plates



Plots During Open Port
Failure Mode Tests
Run 916, 7-L22-163

Figure 72

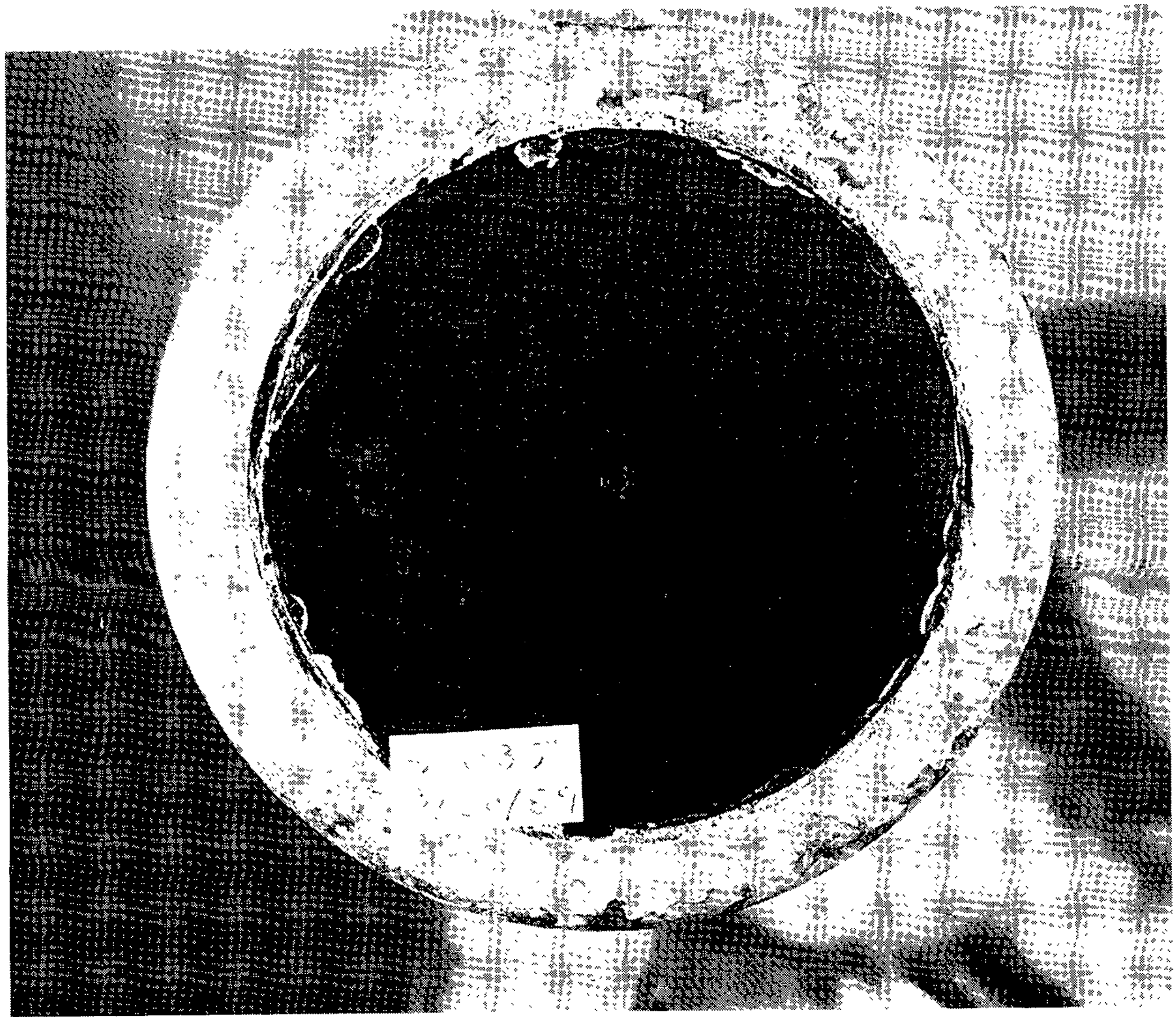


Figure 73 Post Test 2-L22FB-158, 1st Run 2900 degrees F, shown in water cooled holder

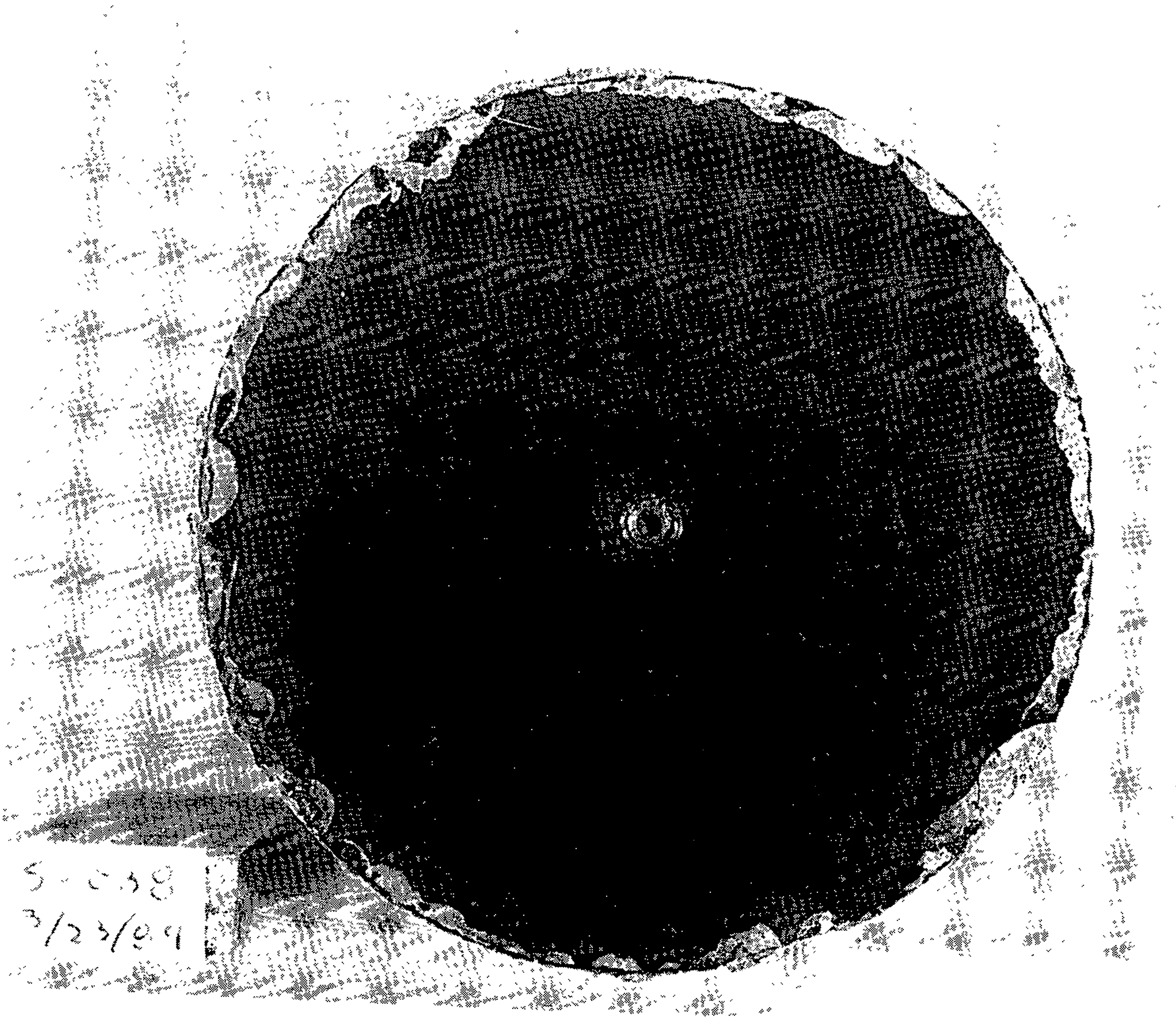


Figure 74 Post Test 2-L22FB-158, 2nd Run 2900 deg. F Tube Failure Test, front view

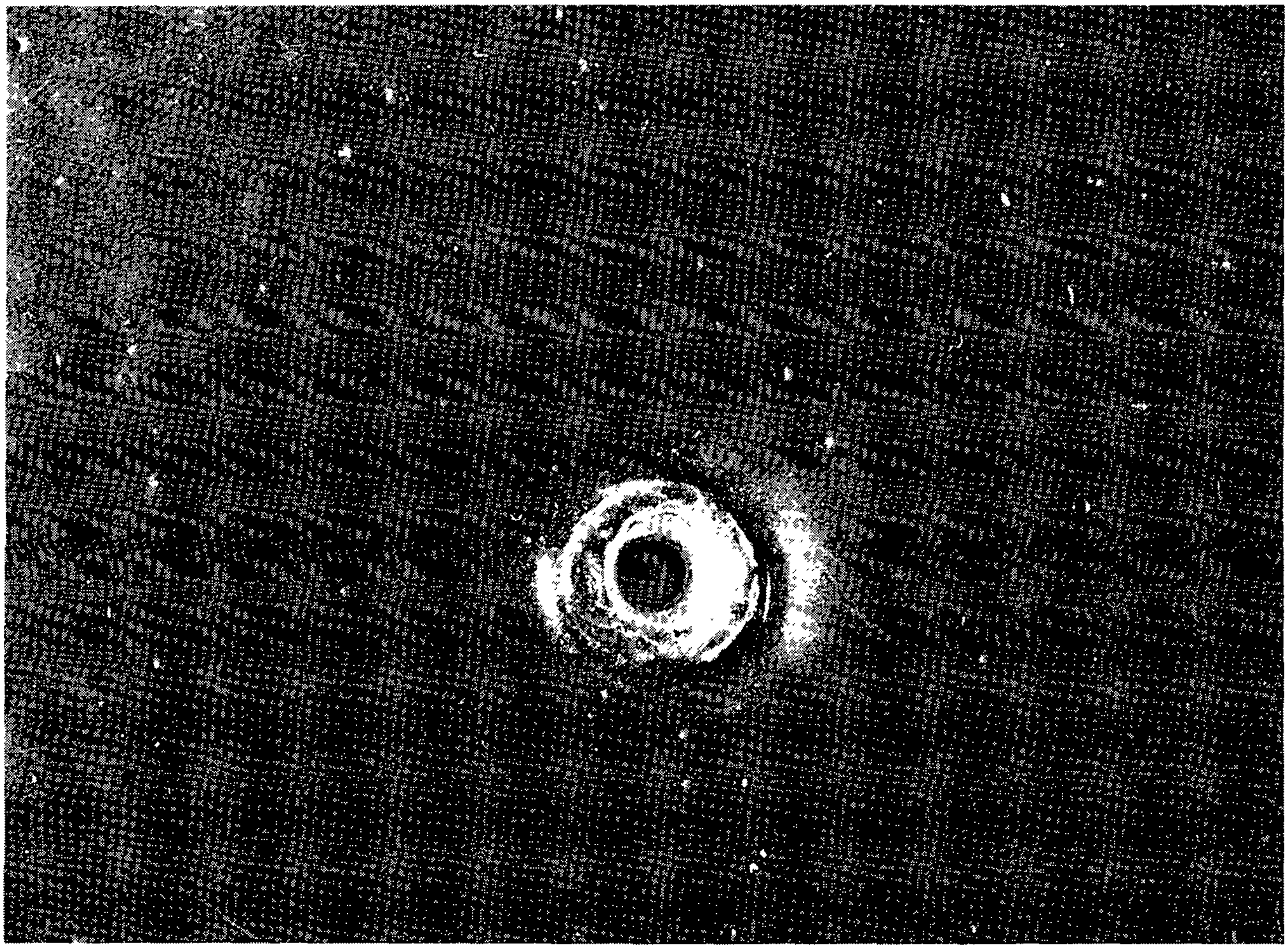


Figure 75 Post Test 2-L22FB-158, 2nd Run 2900 deg. F Tube Failure Test, front view, close-up, showing RCG-Quartz fusion

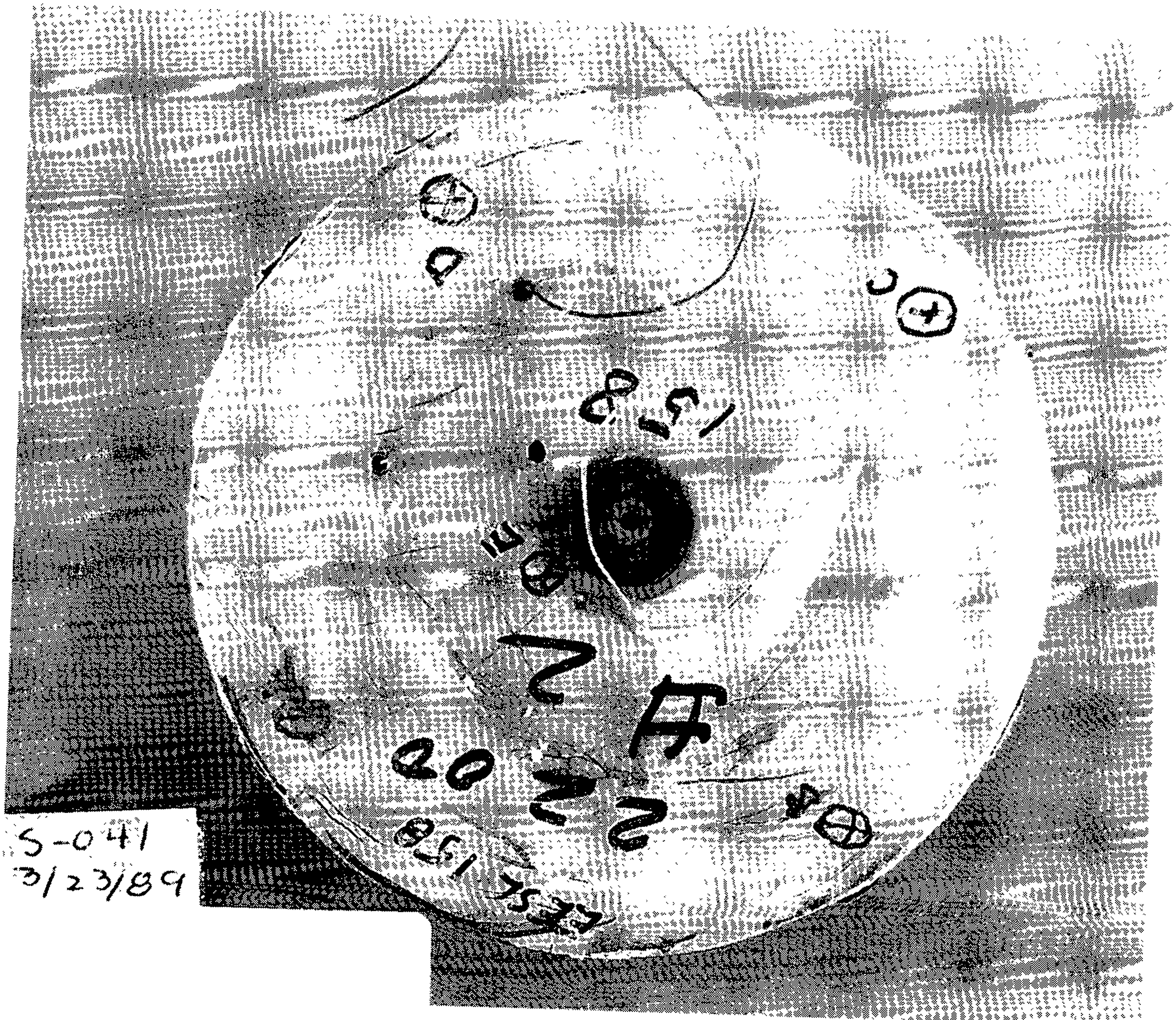


Figure 76 Post Test 2-L22FB-158, 2nd Run 2900 deg. F Tube Failure Test, rear view

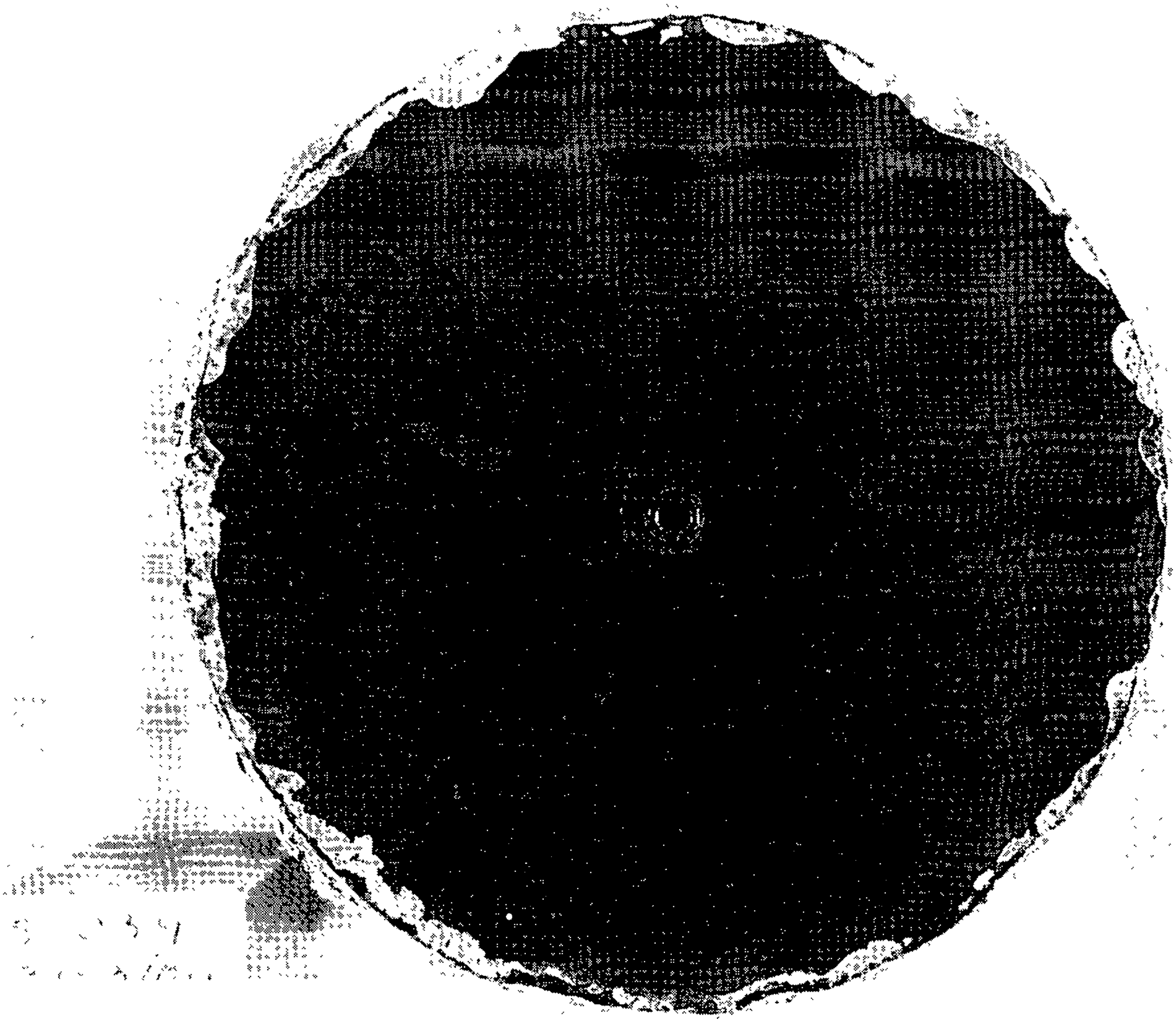


Figure 77 Post Test 7-L22-163, 2nd Run 2900 deg. F Tube Failure Test, front view

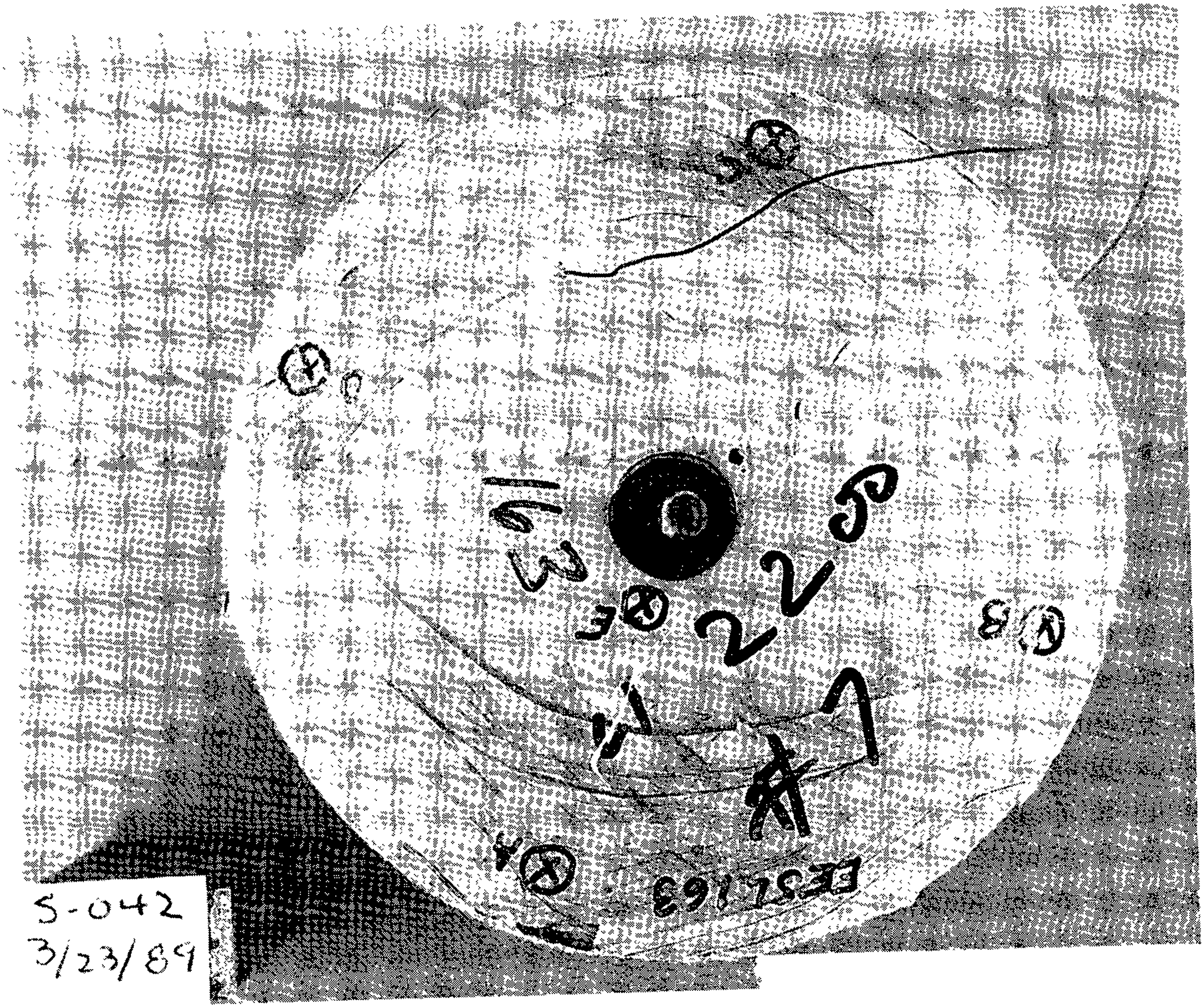


Figure 79 Post Test 2-L22-163, 2nd Run 2900 deg. F
Tube Failure Test, rear view

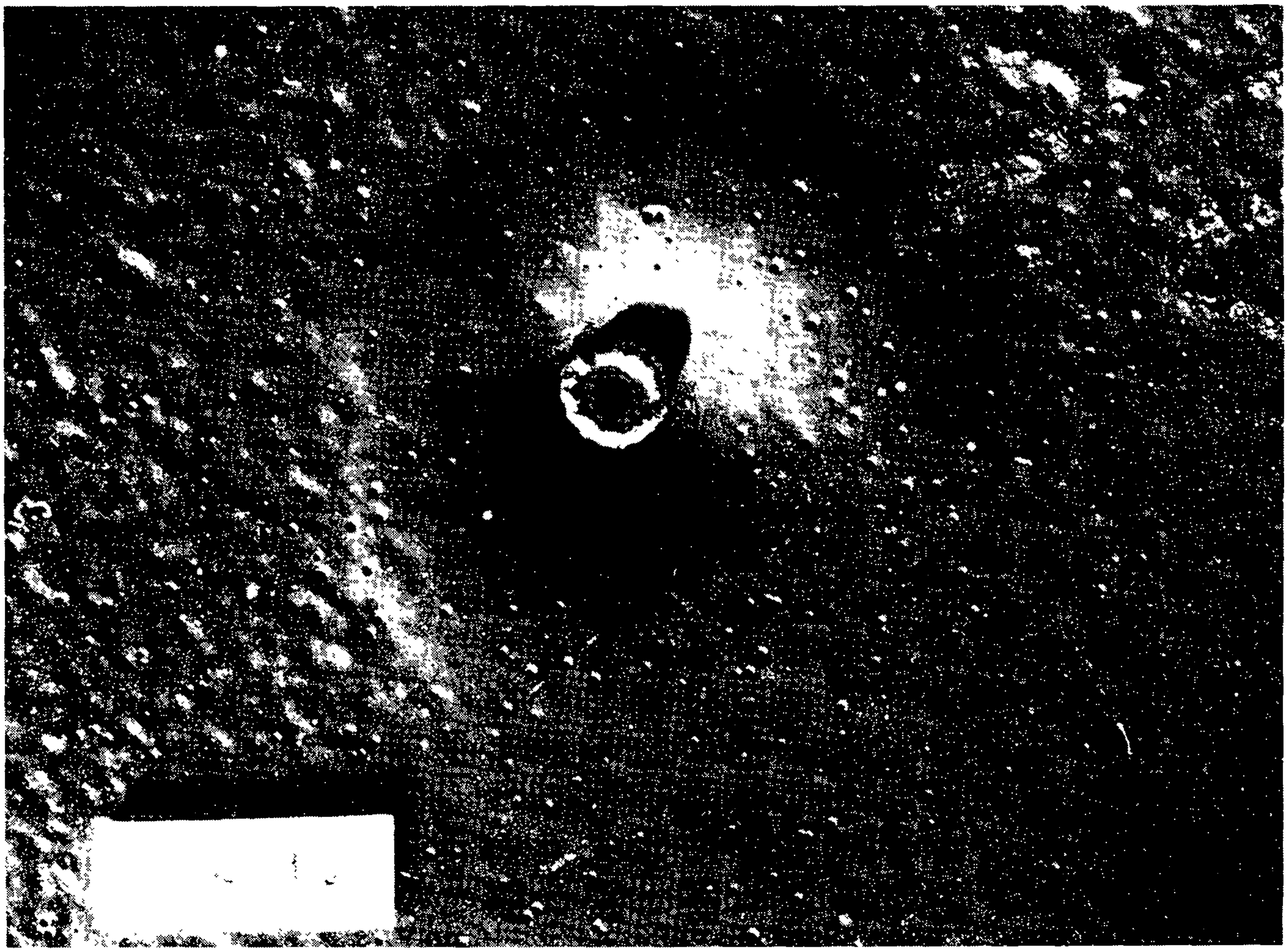


Figure 78 Post Test 7-L22-163, 2nd Run 2900 deg. F Tube Failure Test, front view, close-up, showing tile slumping around quartz tube

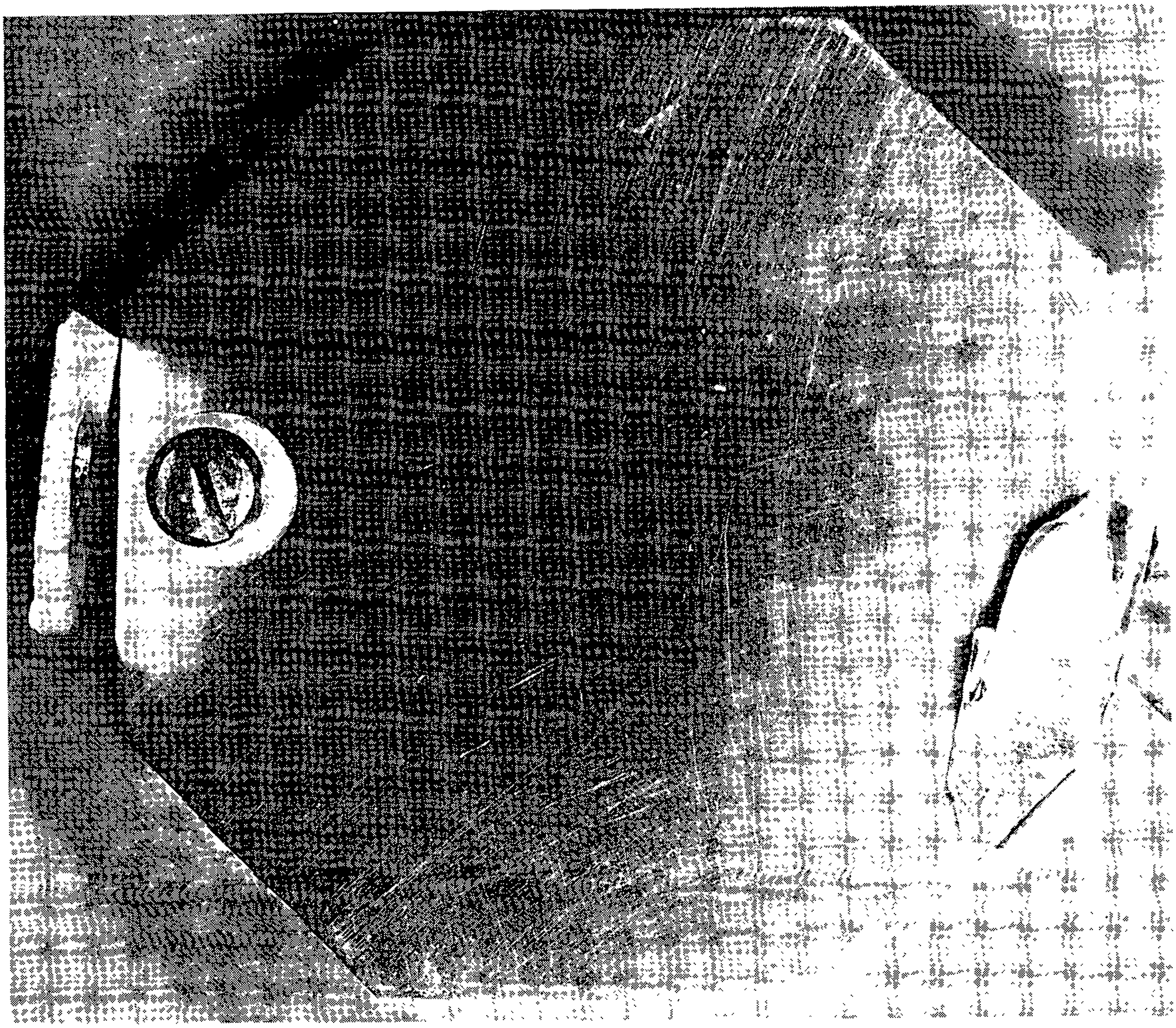
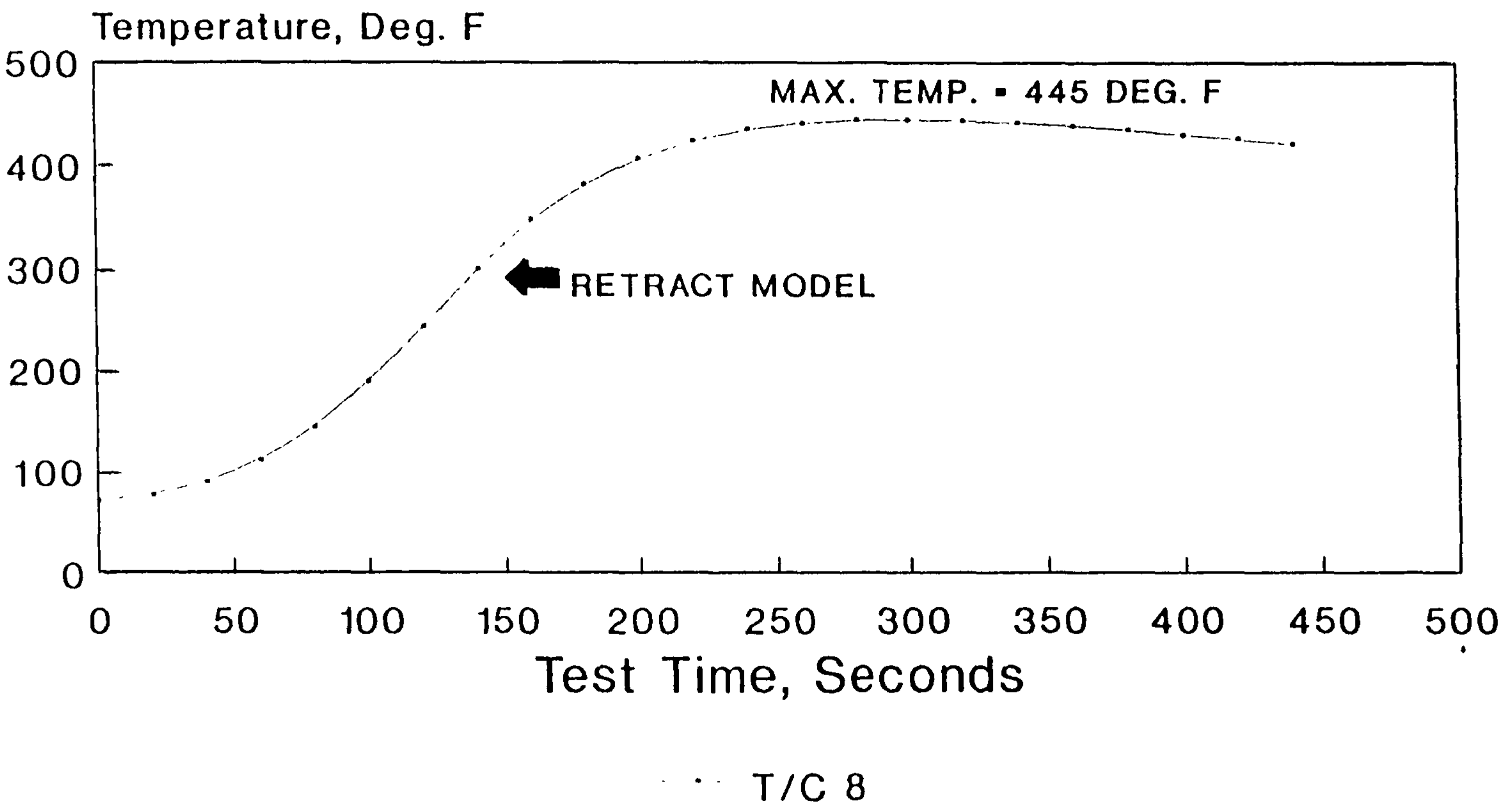


Figure 80 Post Test, 2900 deg. F, Tube Failure Test, showing slug calorimeter with melted quartz deposits

Quartz/Viton Interface

Test Article with Chipped Coating



Temperature Response to 2700
Deg. Surface Temp. for
Test Article 8-F12-164

L.P. MURRAY/LESC

Figure 81

Figure 82 Post Test 8-F12-164, 2nd Run 2700 deg. F Tube Failure Test, front view, showing RCG re-flow

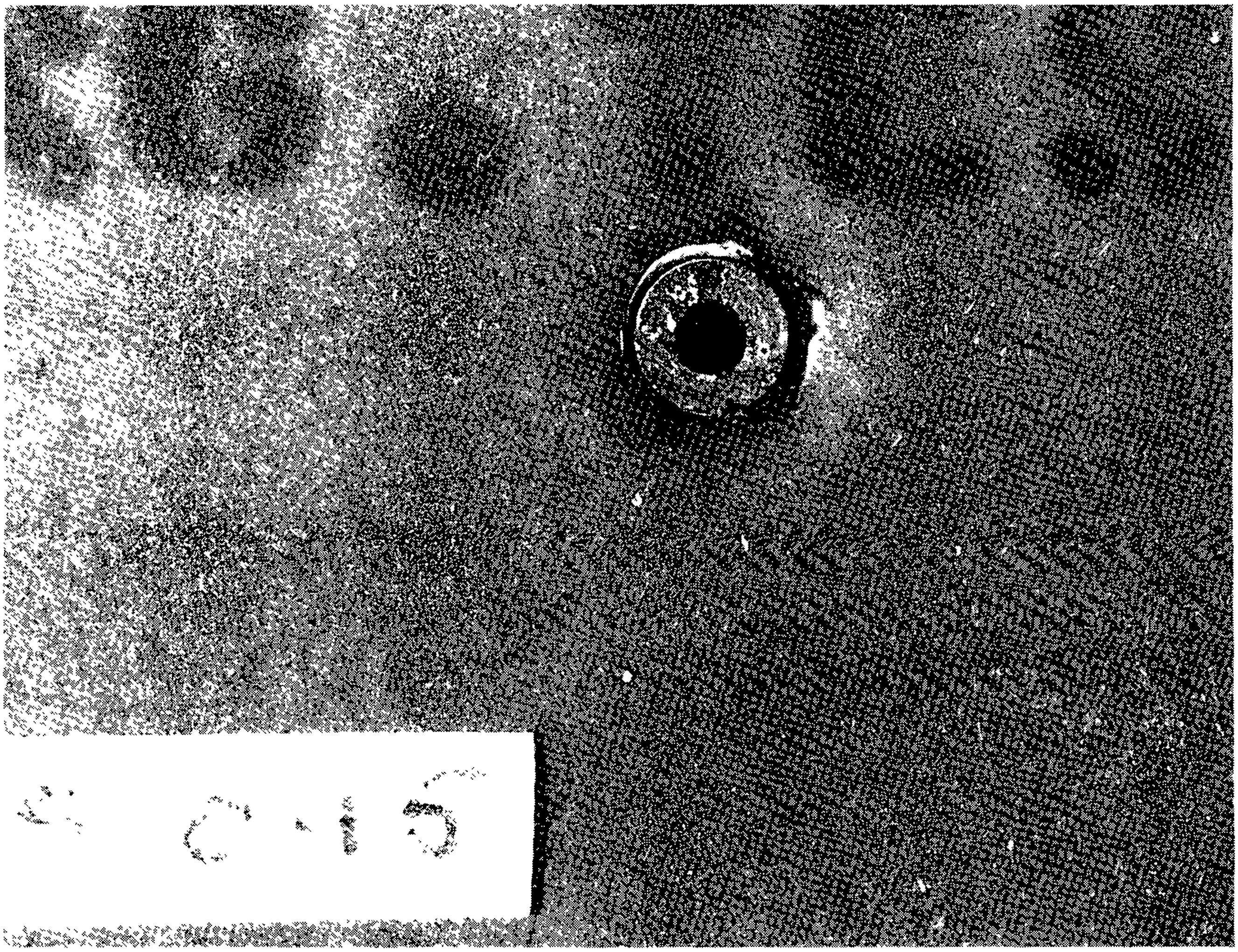


Figure 83 Post Test 8-F12-164, 2nd Run 2700 deg. F Tube Failure Test, front view, close-up showing melted RCG coating in damaged area

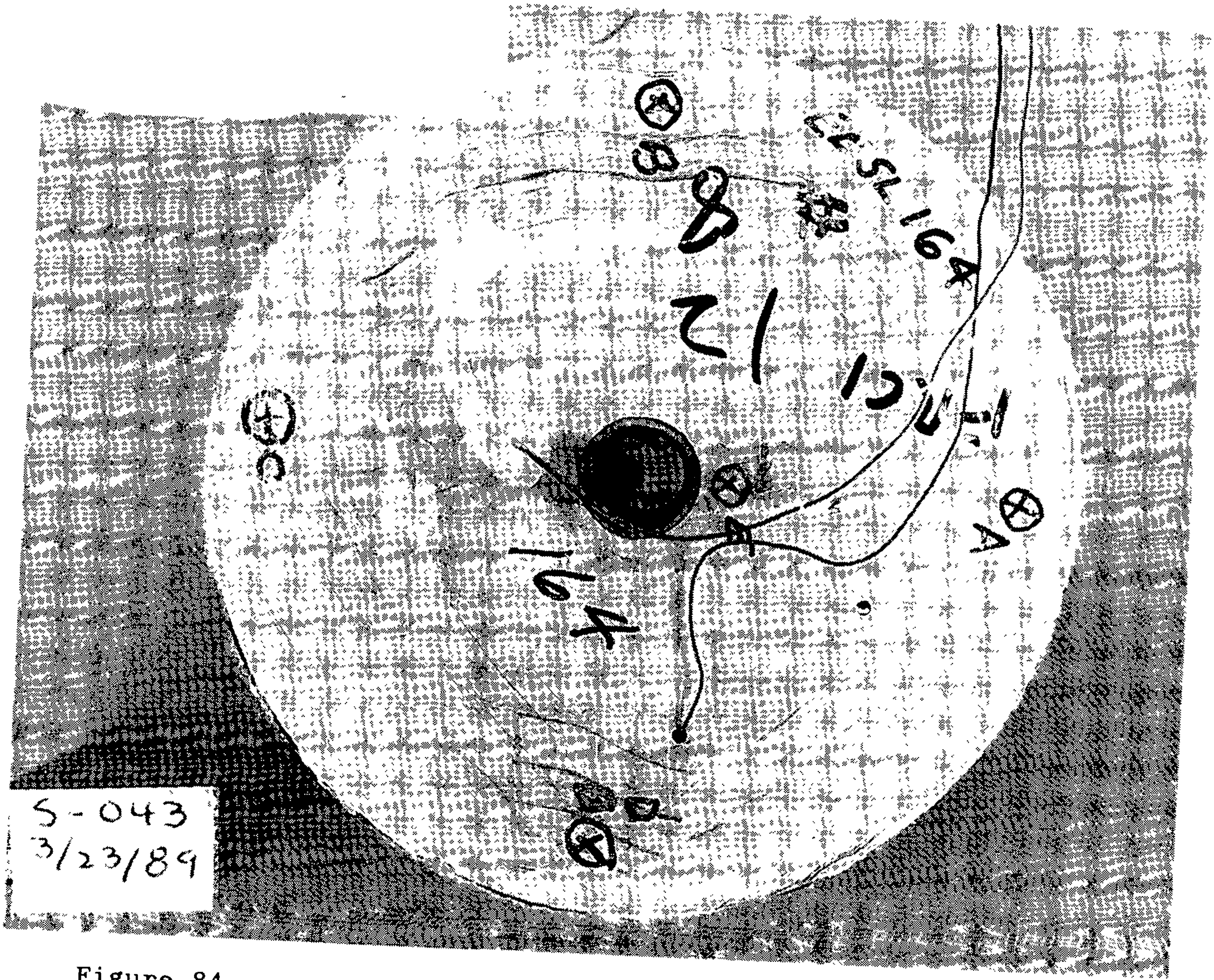


Figure 84

Post Test 8-F12-164, 2nd Run 2700 deg. F

Tube Failure Test, rear view

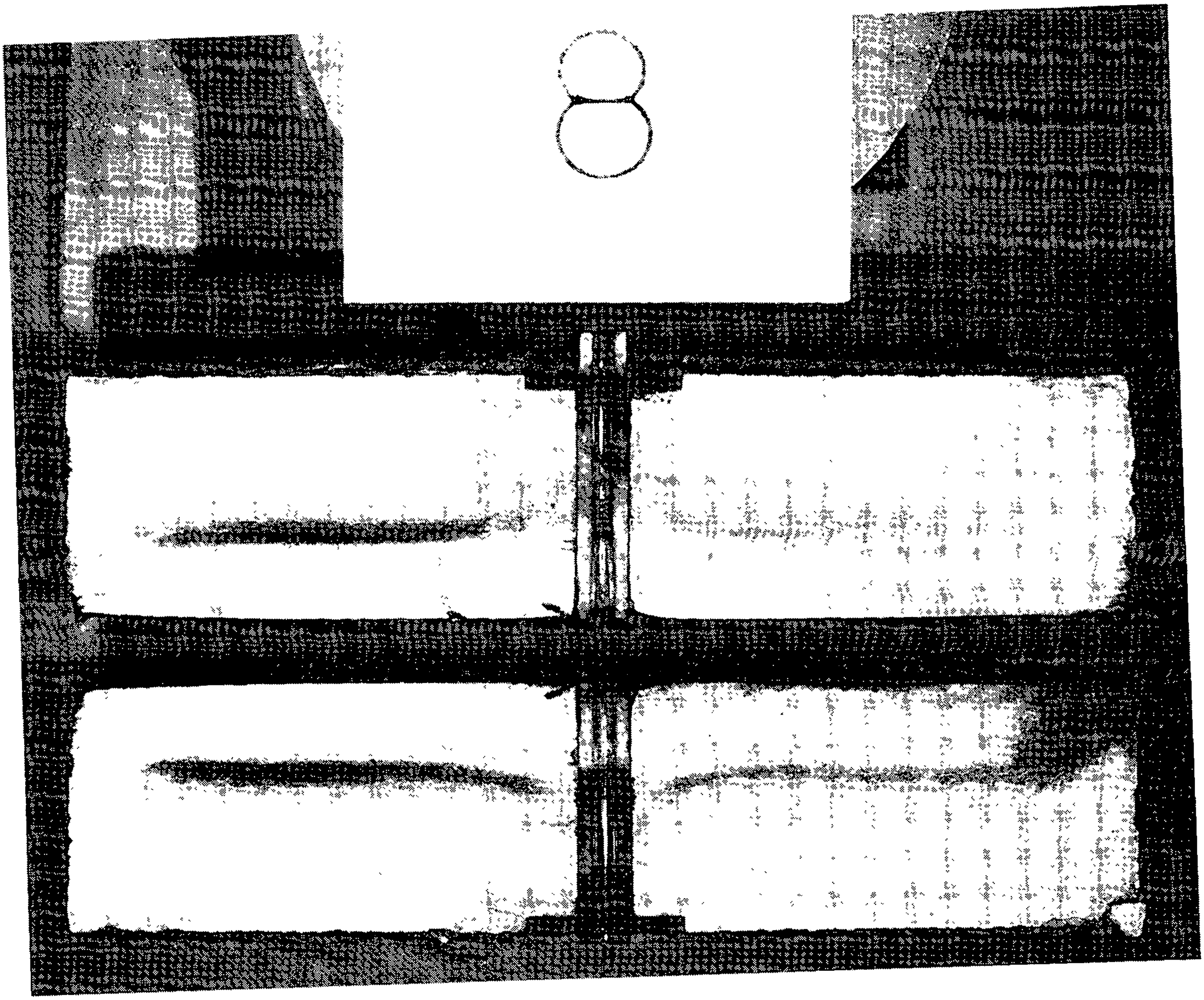


Figure 85 Post Test Dissected 8-F12-164, showing temperature stratas after 2800 & 2700 degrees F runs

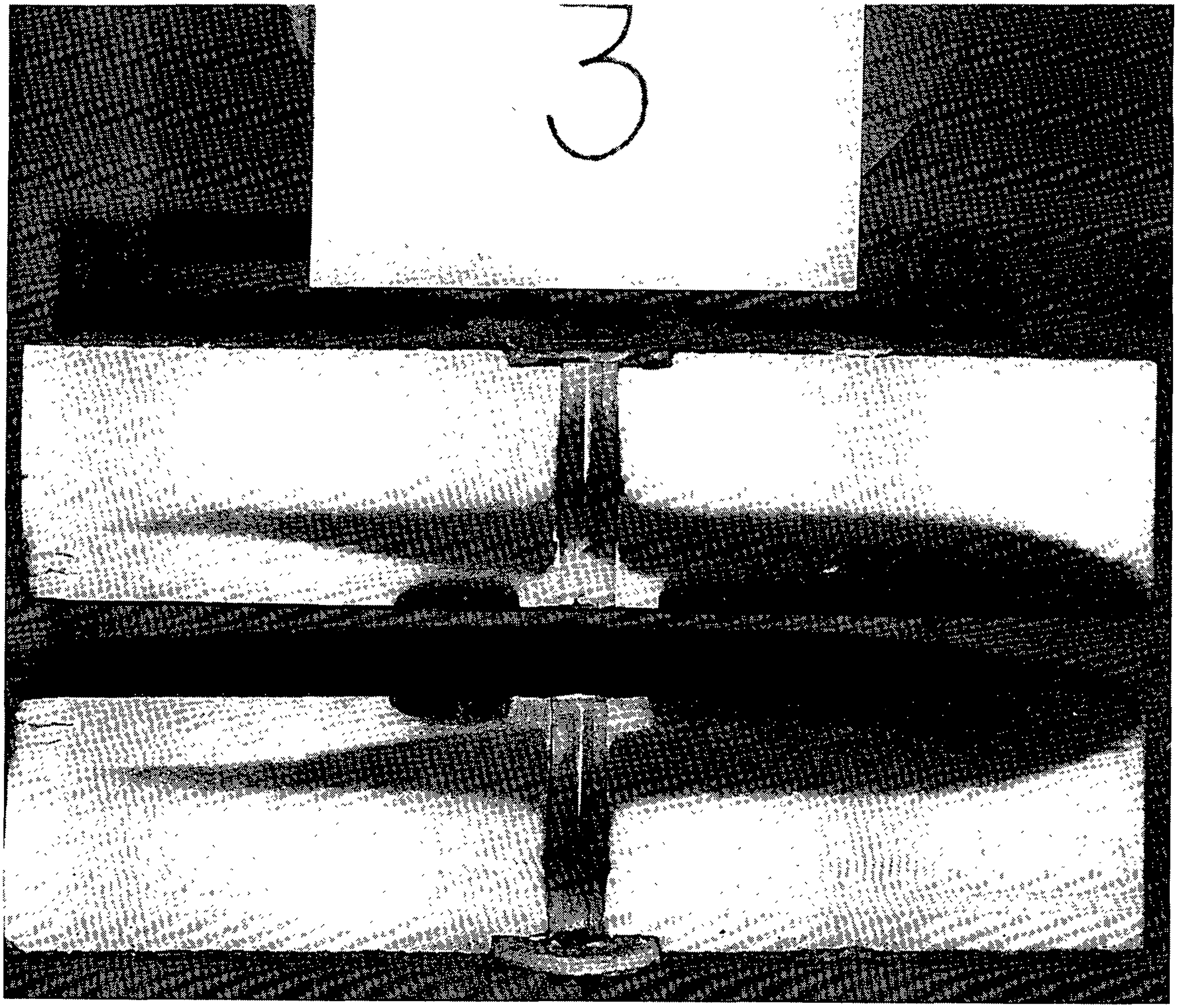


Figure 86 Post Test Dissected 2-L22FB-158, showing temperature stratas after two 2900 degree F runs.

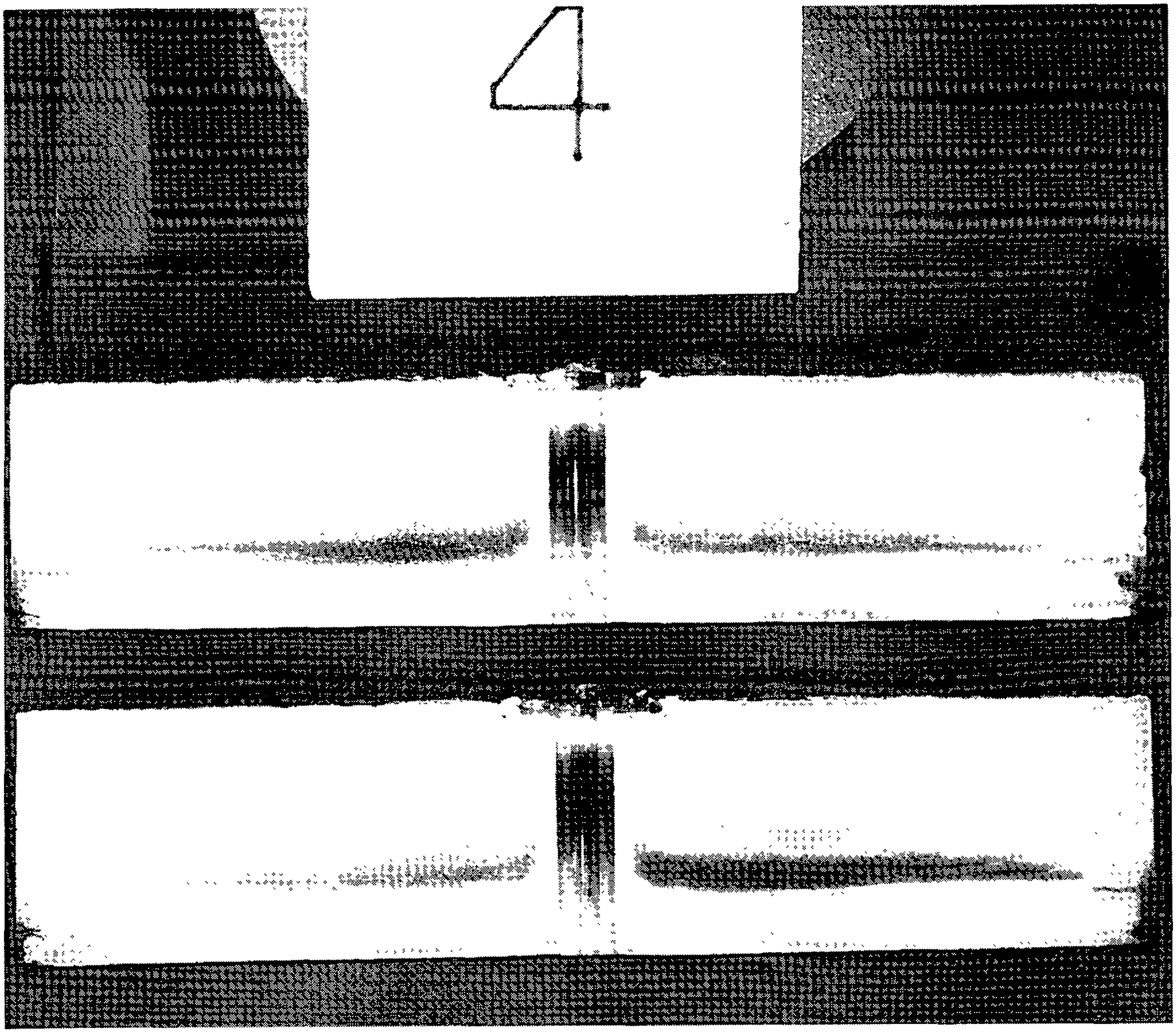


Figure 87 Post Test Dissected 3-F12FB-159, showing temperature stratas after a 2700 degrees F run.

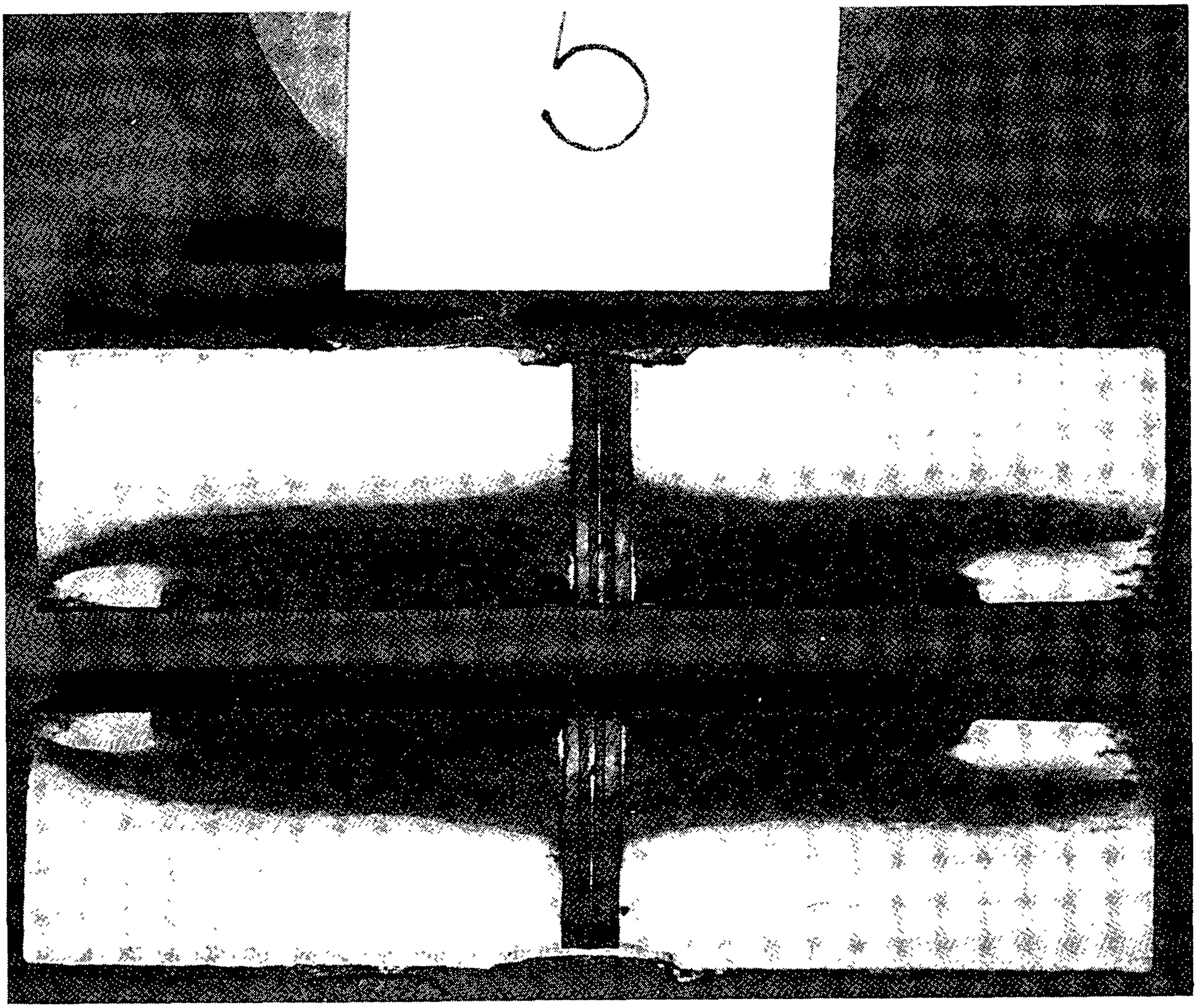


Figure 88 Post Test Dissected 4-F12FB-160, showing temperature stratas after a 2800 degree F run.

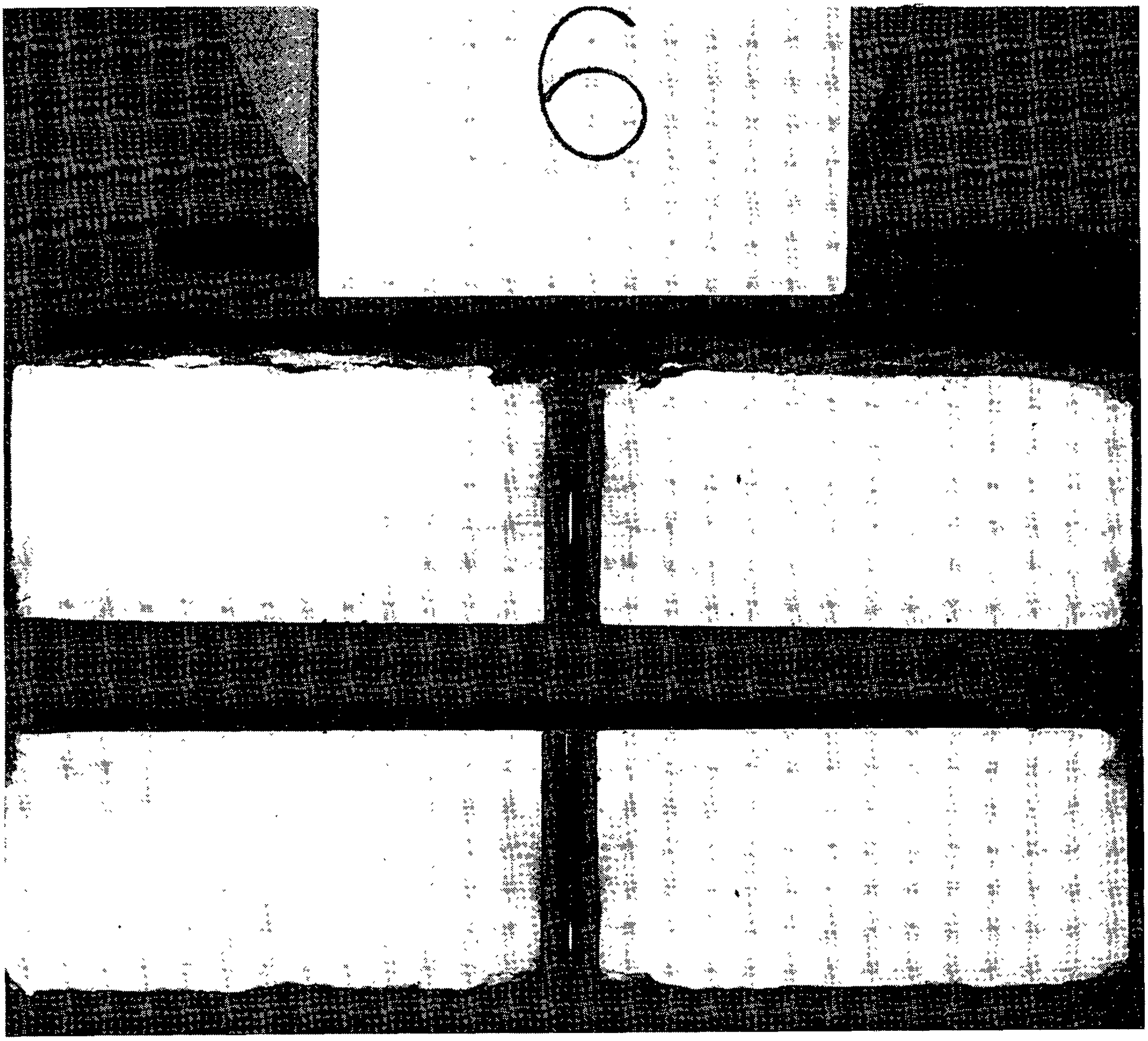


Figure 89 Post Test Dissected 5-F12-161, showing temperature stratas after a 2700 degree F run.

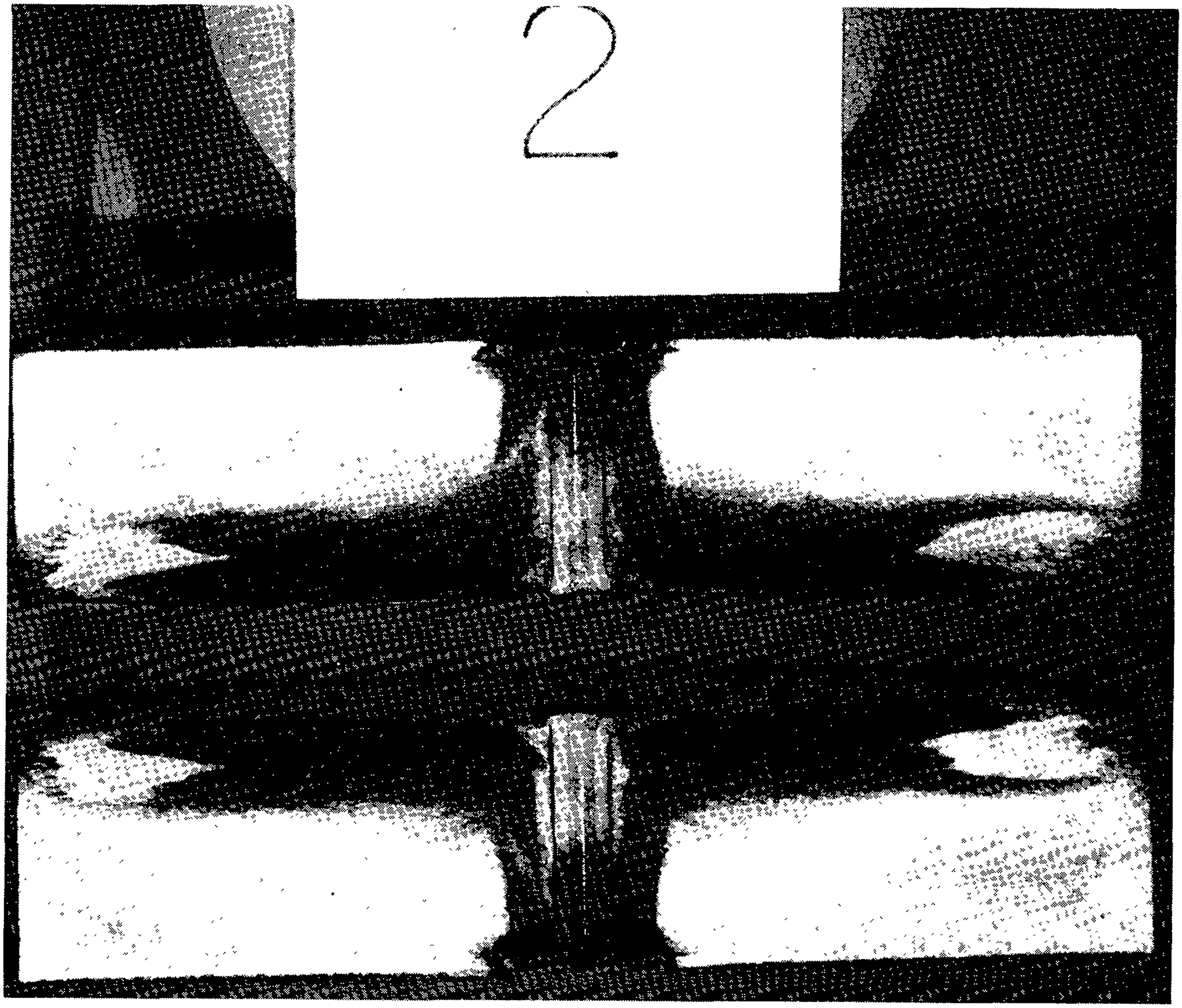


Figure 90 Post Test Dissected 6-L9-162, showing temperature stratas after a 2300 degree F run.

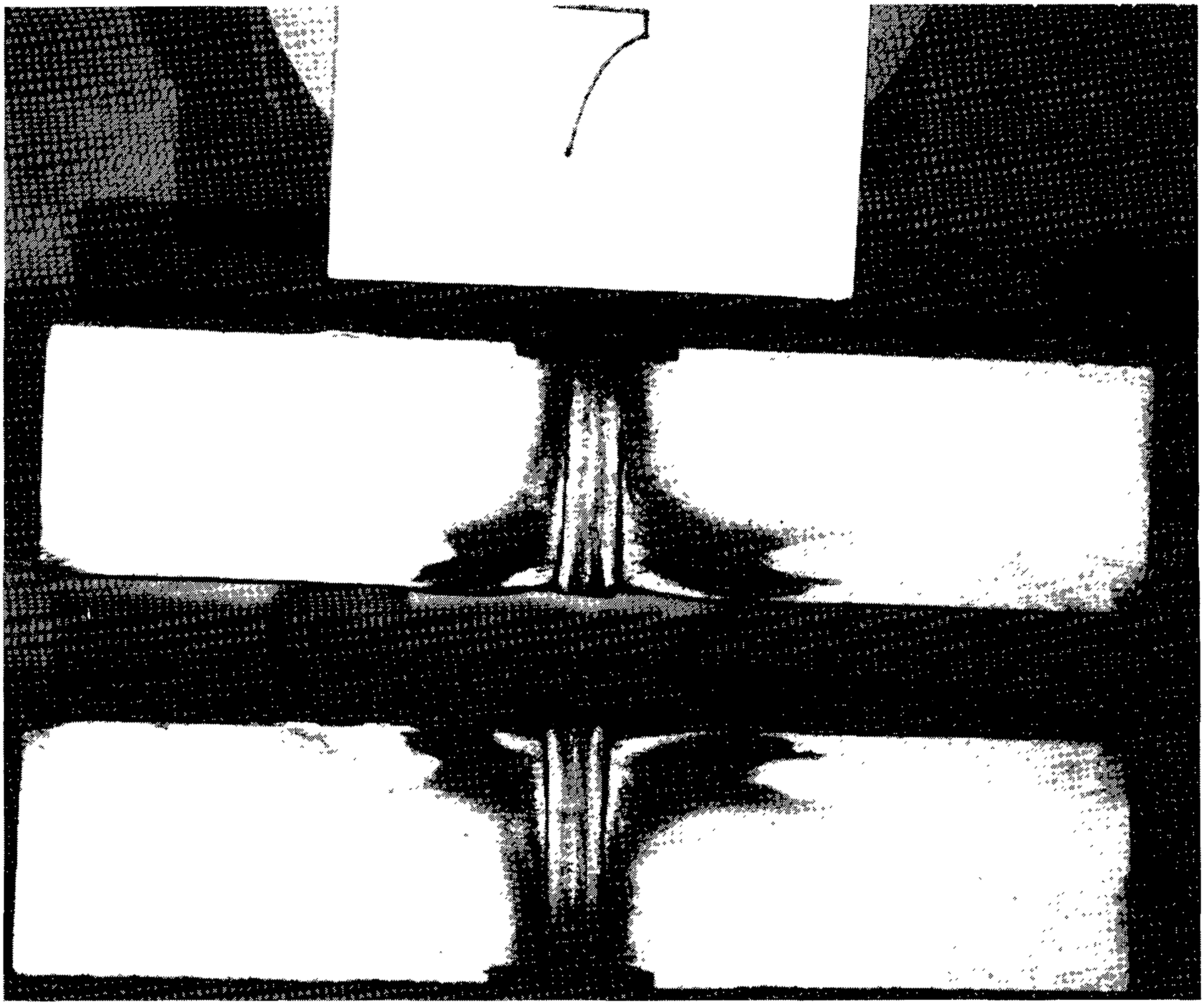


Figure 91 Post Test Dissected 7-L22-163, showing temperature stratas after two 2900 degree F runs.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

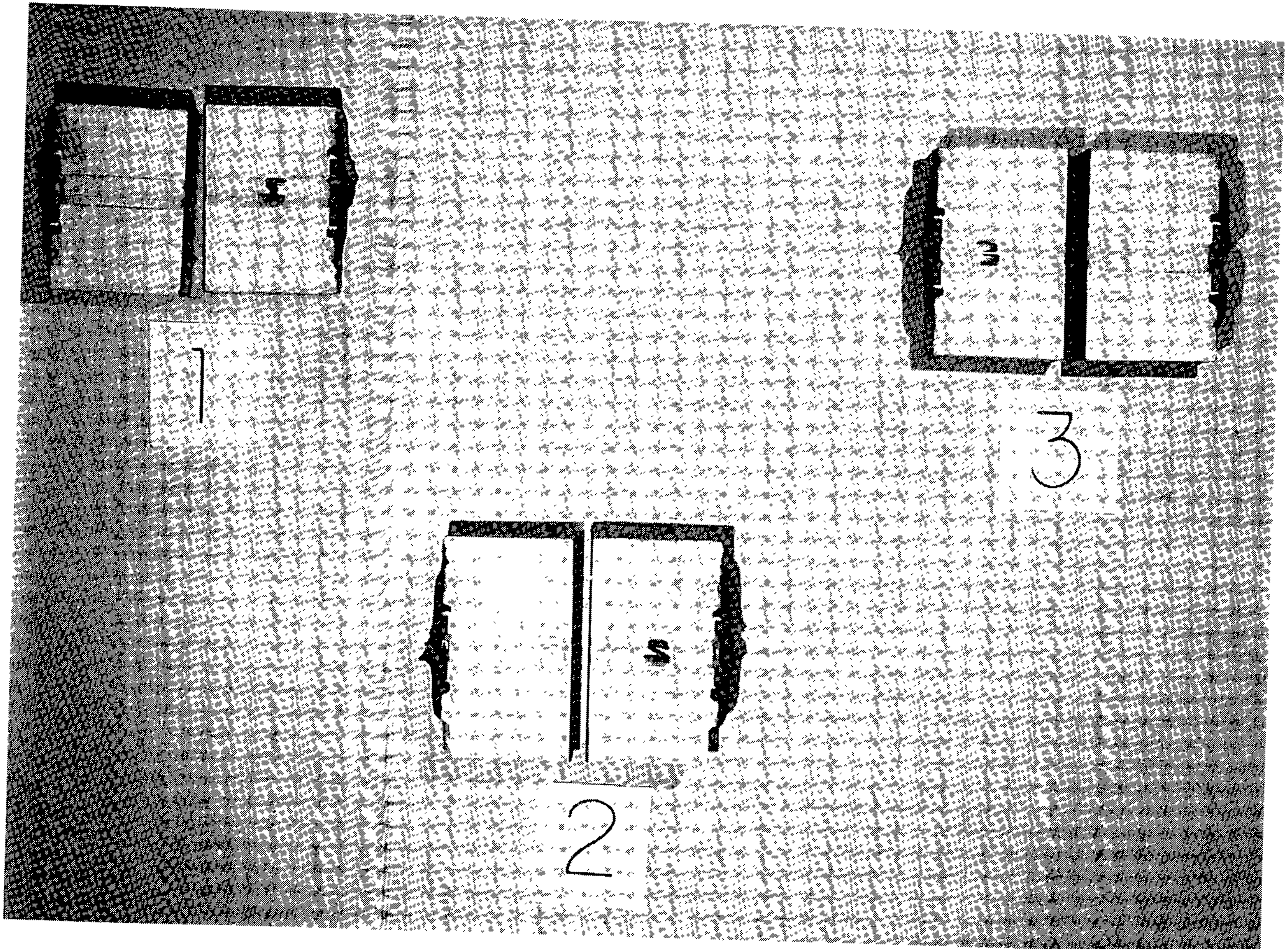


Figure 92 Post Test Dissected Bending Test Articles, showing fully bonded tubes.

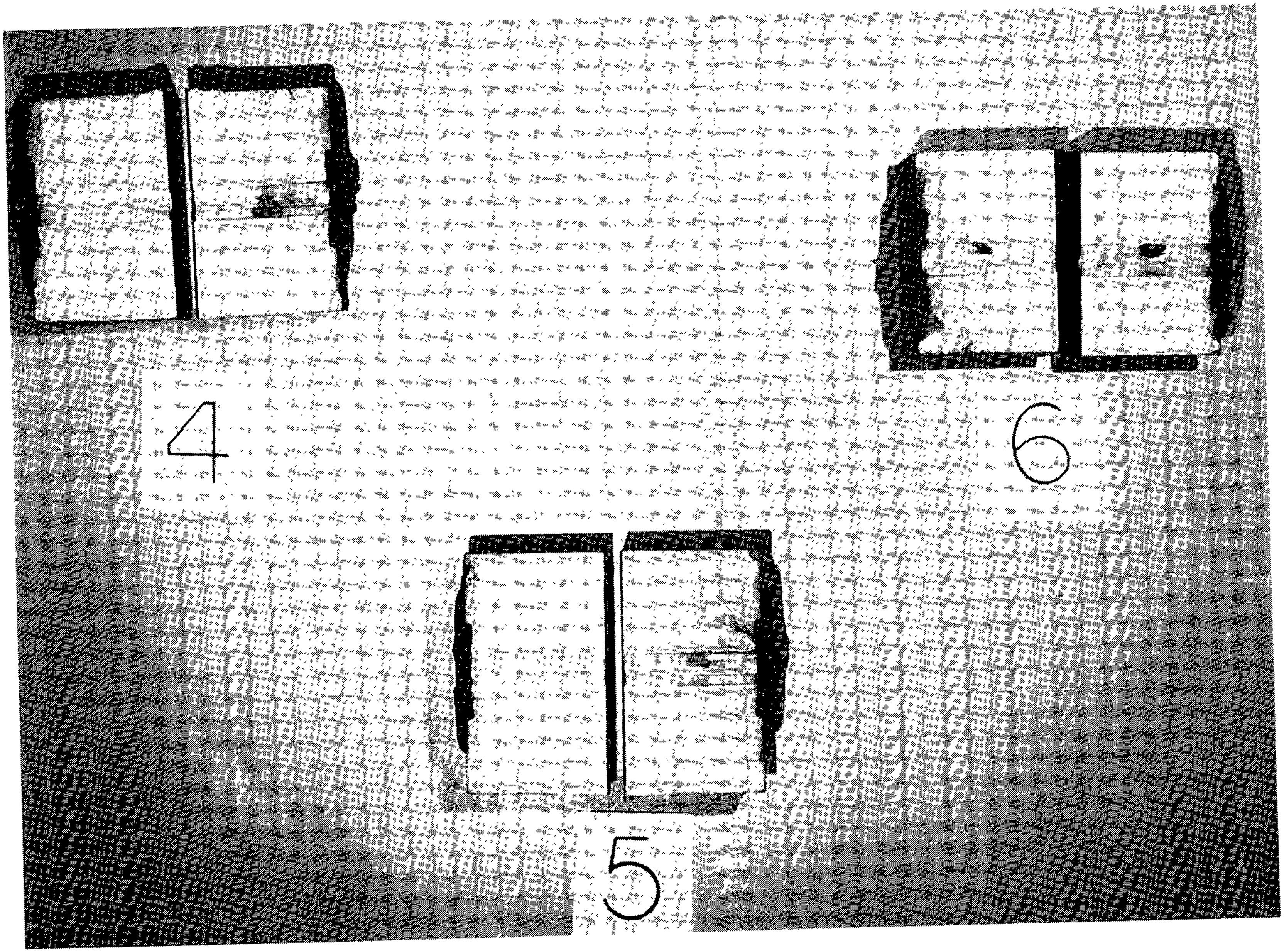


Figure 93 Post Test Dissected Bending Test Articles, showing partially bonded tubes.

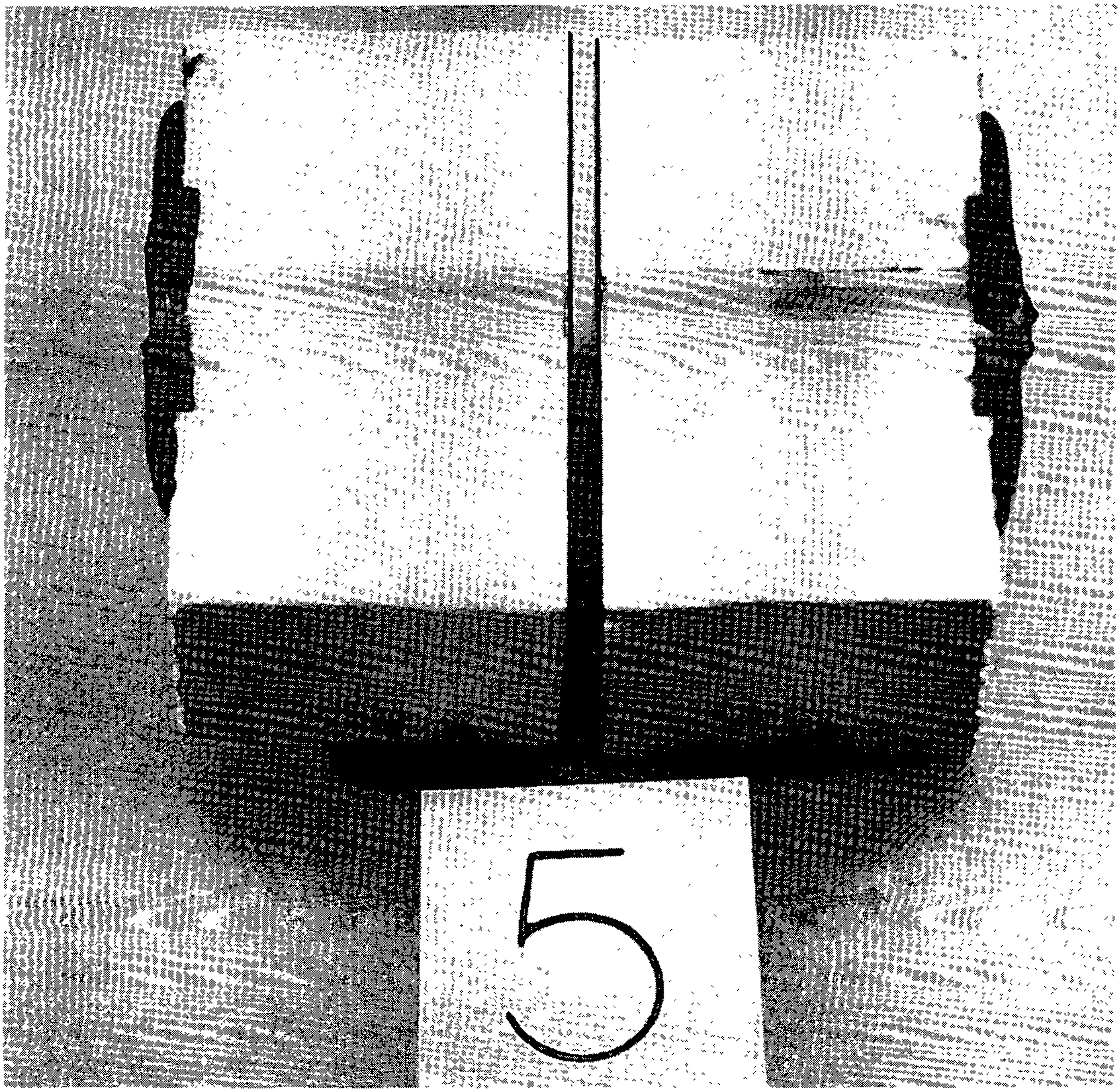


Figure 94 Post Test Dissected Bending Test Articles, showing close-up of partially bonded tubes.

BLACK AND WHITE PHOTOGRAPH

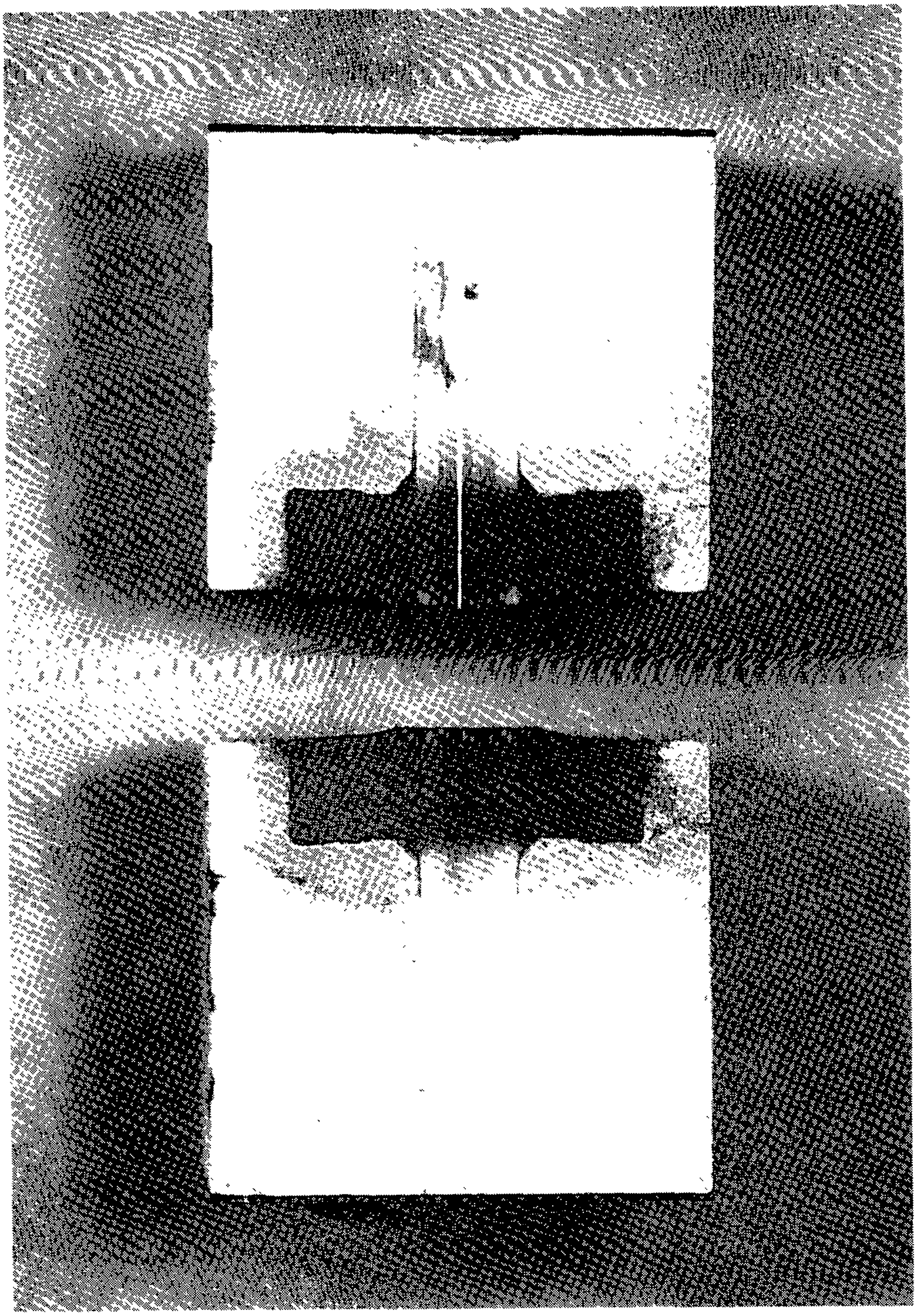
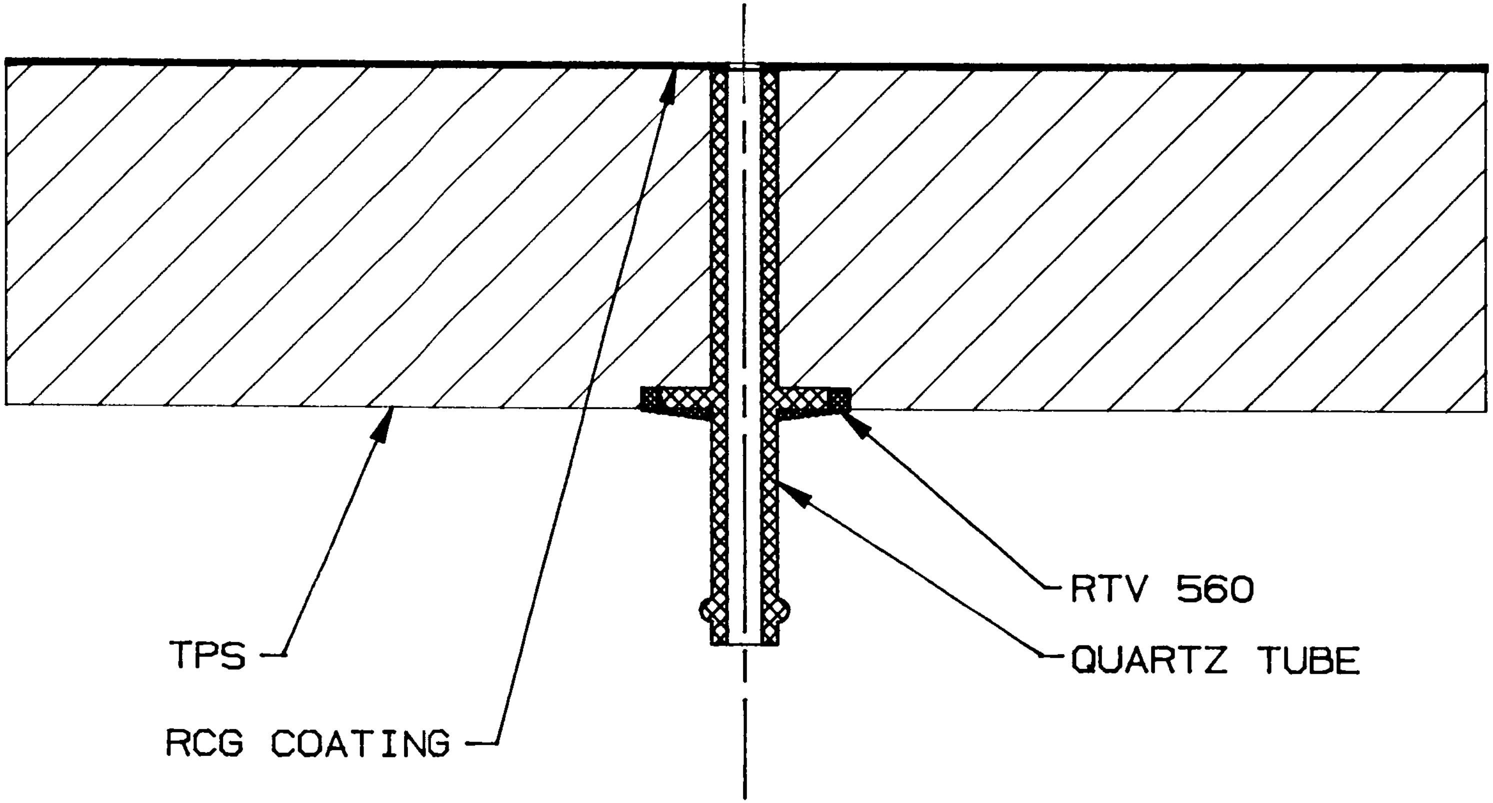


Figure 95 Post Test Dissected Bent Tube Bending Test Articles, showing a close-up of partially bonded tubes.



BONDING TECHNIQUE

FIGURE 96

AFE PD/ADS LUMPED CAPACITANCE MODEL

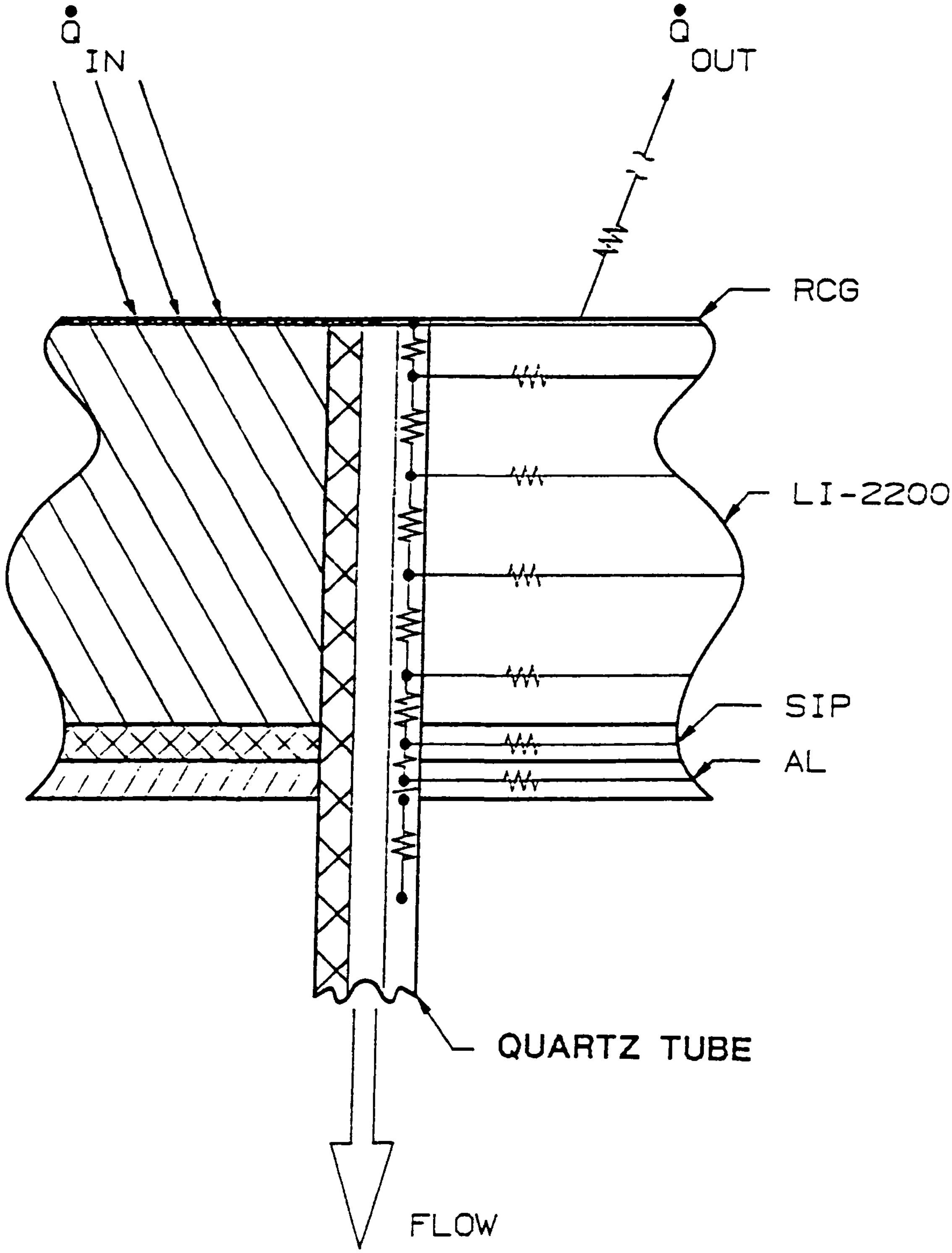


FIGURE 97

AFE PD/ADS Thermal Analysis–BL5 Heating

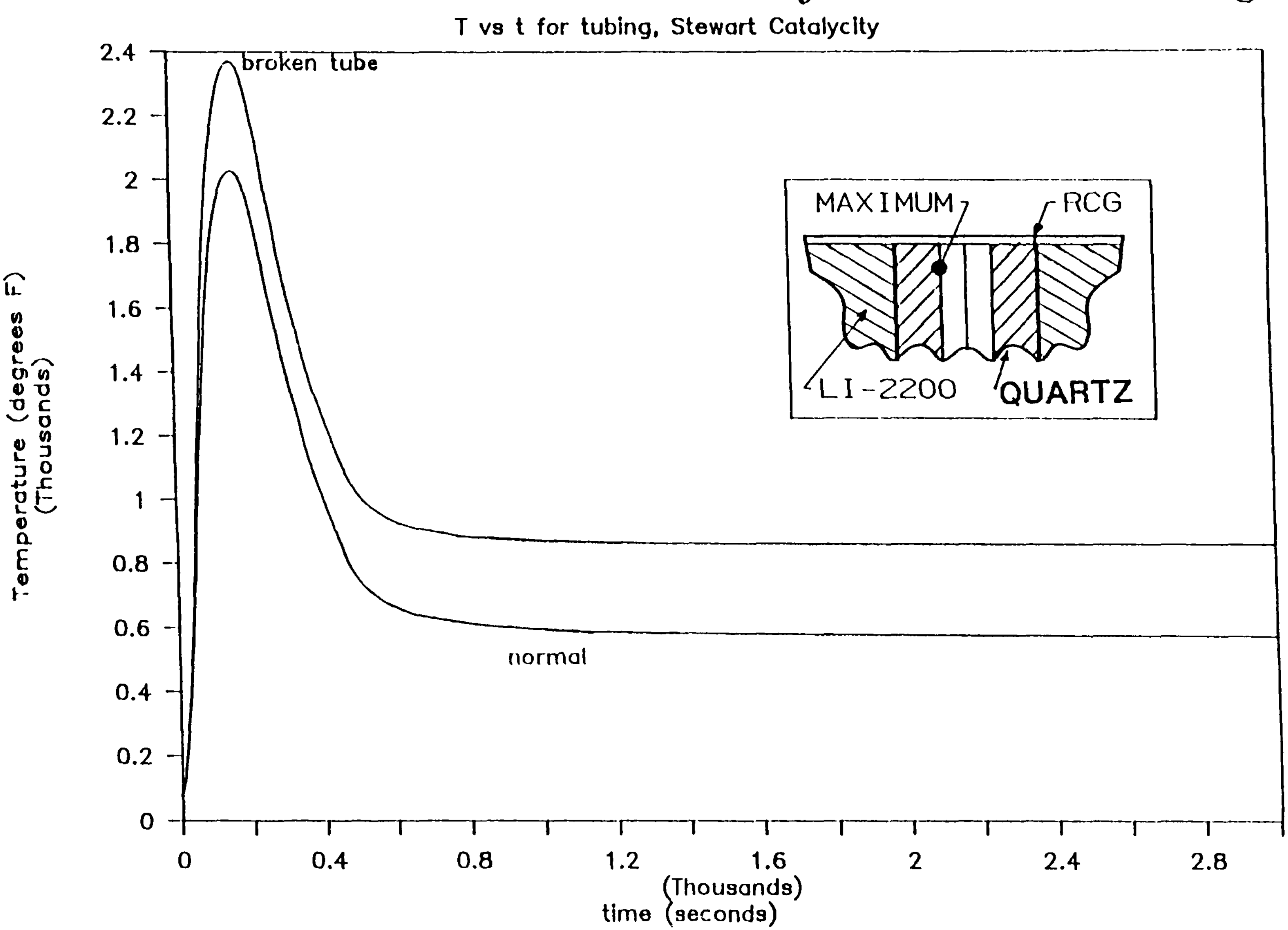


FIGURE 98

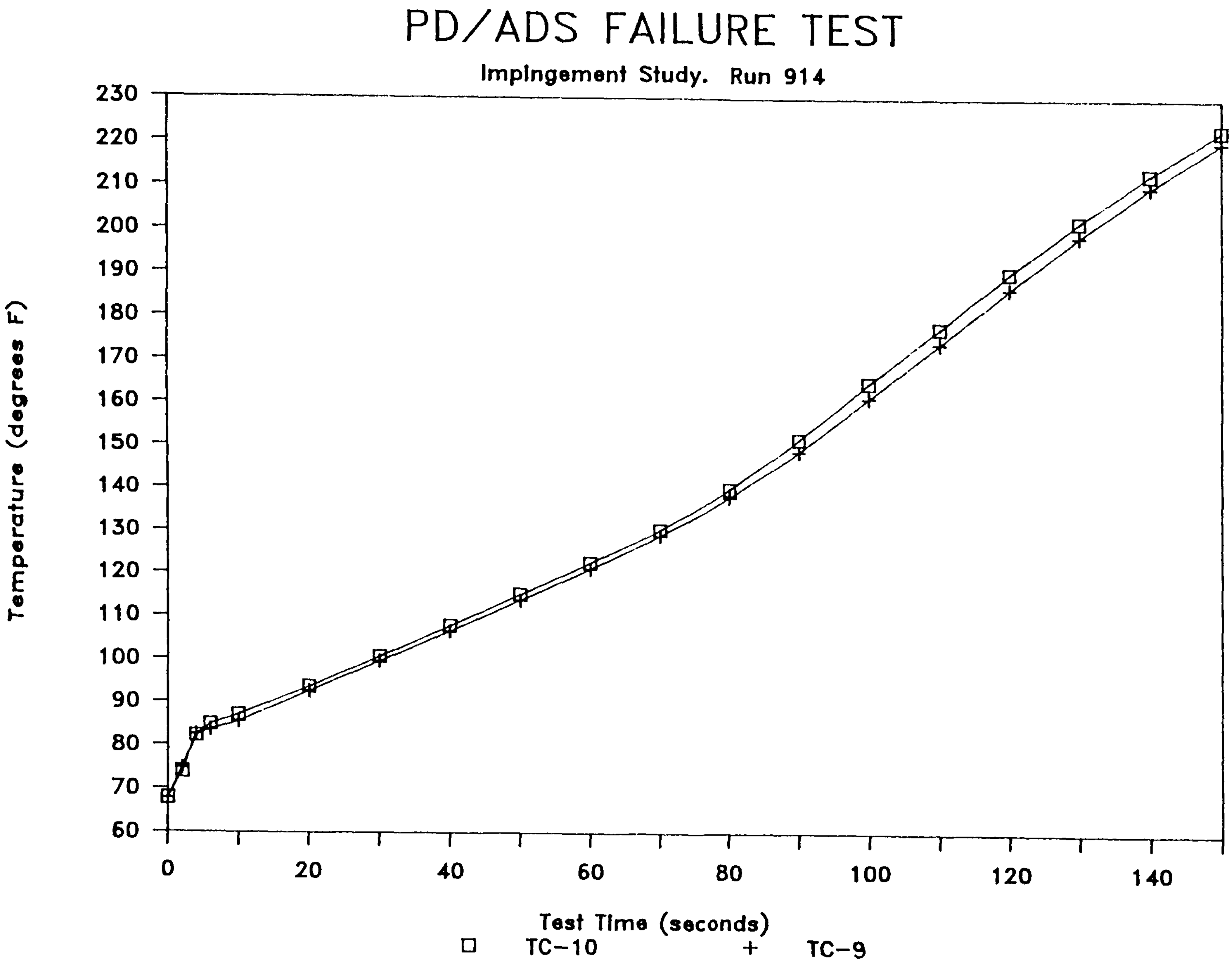

PD/ADS FAILURE TEST
Impingement Study. Run 914
Temperature (degrees F)
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
0
20
40
60
80
100
120
140
Test Time (seconds)
TC-10
TC-9

FIGURE 99

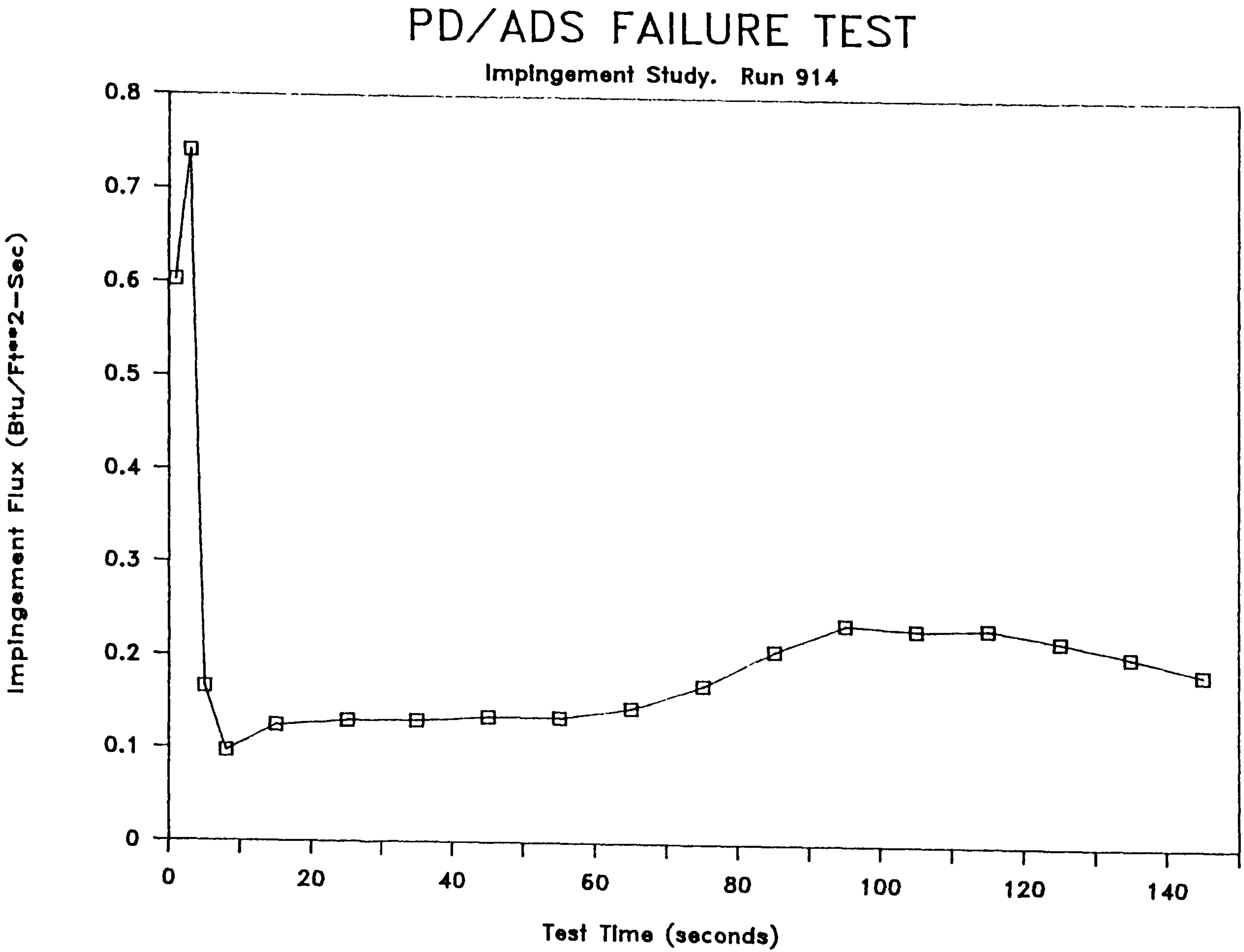

PD/ADS FAILURE TEST
Impingement Study. Run 914
Impingement Flux (Btu/Ft**2-Sec)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
Test Time (seconds)

FIGURE 100

PD/ADS ARC-JET TESTING

TEST NUMBER	MATERIAL	RUN NUMBER	BONDING	T_{Wall} (°F)	Q_{CONV} (BTU/FT^2*SEC)
2-L22FB-158	LI-2200	912	FULL	2830	49.90
2-L22FB-158	LI-2200	914	FULL	2600	37.57
3-F12-159	FRCI-12	907	FULL	2697	42.57
4-F12FB-160	FRCI-12	909	FULL	2730	47.81
5-F12-161	FRCI-12	908	RTV	2702	42.73
7-L22-163	LI-2200	911	RTV	2790	54.61
7-L22-163	LI-2200	916	RTV	2600	37.57
8-F12-164	FRCI-12	910	RTV	2720	42.73
8-F12-164	FRCI-12	915	RTV	2650	40.09

Note: Temperatures from optical pyrometer with e=0.90

FIGURE 101

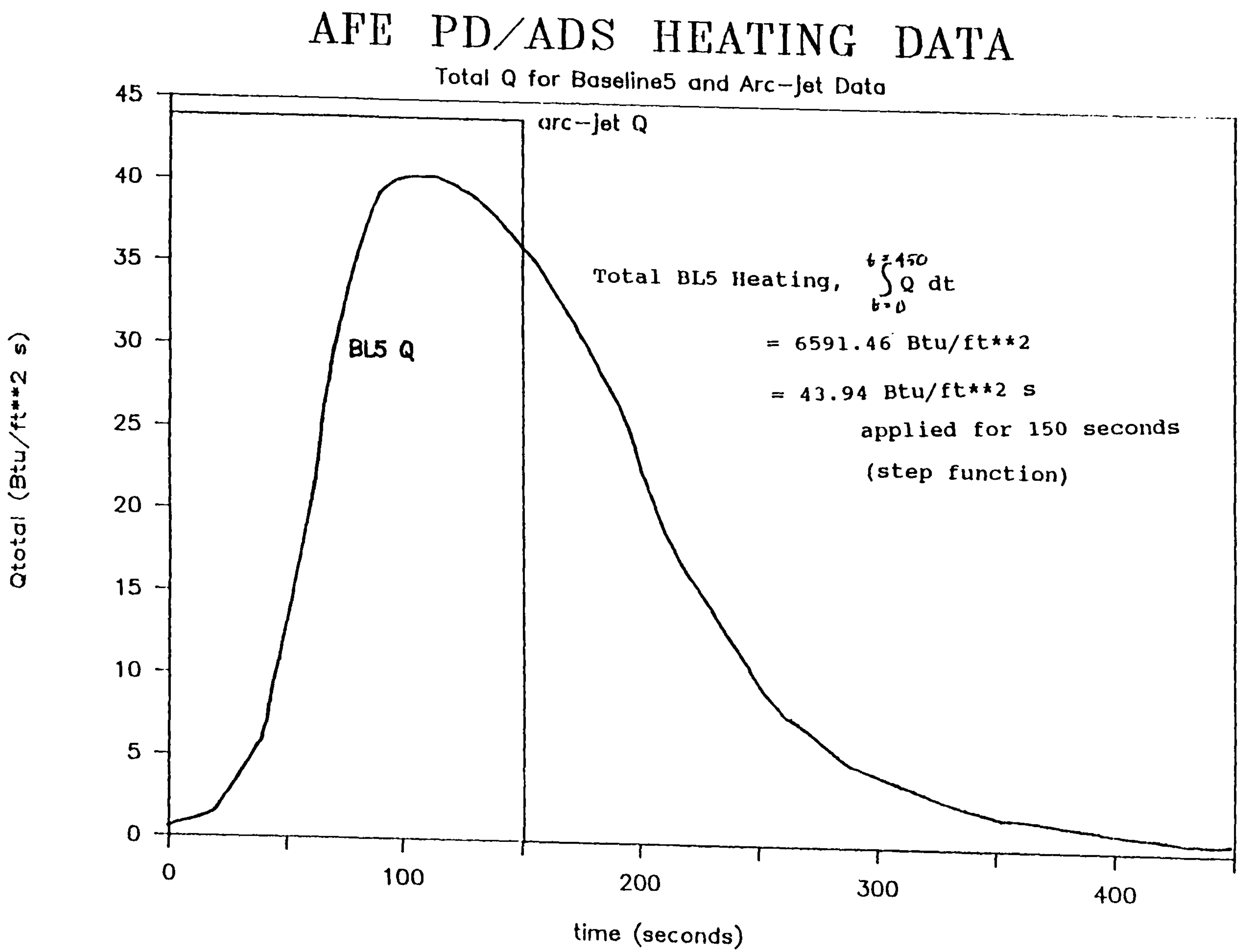
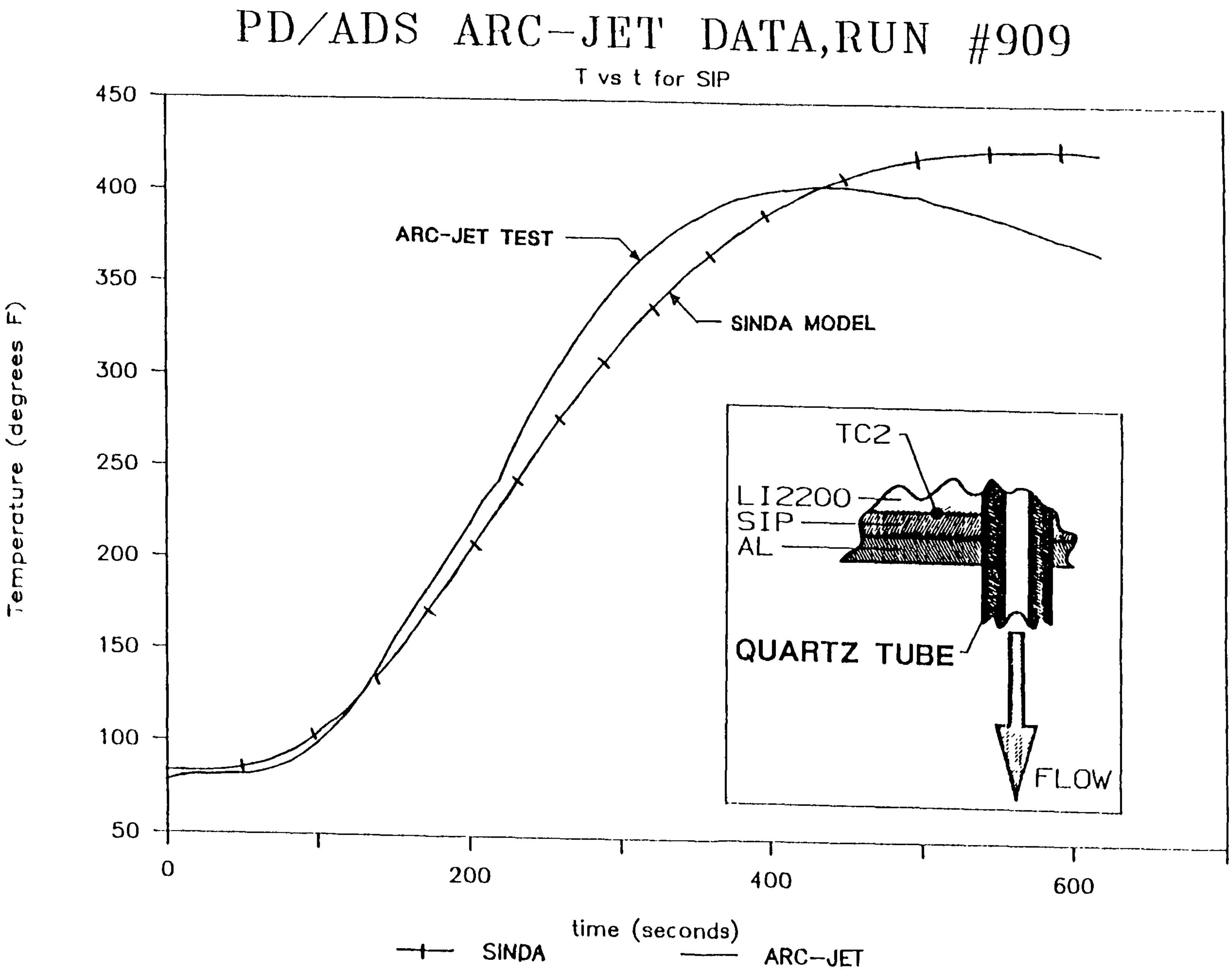

AFE PD/ADS HEATING DATA
Total Q for Baseline5 and Arc-Jet Data
arc-jet Q
BL5 Q
Total BL5 Heating, $\int_{t=0}^{t=450} Q \, dt$
= 6591.46 Btu/ft**2
= 43.94 Btu/ft**2 s
applied for 150 seconds
(step function)
Qtotal (Btu/ft**2 s)
45
40
35
30
25
20
15
10
5
0
0
100
200
300
400
time (seconds)

FIGURE 102



PD/ADS ARC-JET DATA,RUN #909
T vs t for SIP
450
400
350
300
250
200
150
100
50
Temperature (degrees F)
0
200
400
600
time (seconds)
ARC-JET TEST
SINDA MODEL
TC2
LI2200
SIP
AL
QUARTZ TUBE
FLOW
SINDA
ARC-JET

FIGURE 103

APPENDIX A

AERO-THERMAL TEST PLAN

JSC Memorandum ES3-88-3M

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas
77058

NASA

JAN. 24 1989

Reply to Attn of ES3-88-3M

TO: Distribution

FROM: ES32/Donald J. Tillian

SUBJECT: Test plan for Thermal Performance Tests of Aeroassist Flight Experiment (AFE) Pressure Port Configuration in the JSC 10MW Arc Heated Facility

The purpose of this memorandum is to transmit test requirements for the subject test program. In particular these tests are intended to evaluate the thermal performance of pressure port configurations for the AFE.

1.0 Background

Acquisition of accurate pressure data is of critical importance to the success of the AFE program. Since the AFE experiences high heating conditions (temperatures >2700°F), development activities are required for the pressure port that penetrates the AFE TPS tile. NASA JSC and Langley have become jointly involved in the development activities for the pressure ports. The NASA Langely concept involves machining a hole through the coated FRCI-12 tile, followed by bonding of the quartz tube with ceramic cement. The JSC concept involves installation of the quartz tube and then application of the RCG coating. An arc jet test program has been developed to establish a data base for selection of the most promising configuration for the AFE application.

2.0 Objective

The objective of this test program are to (1) acquire thermal performance data and (2) evaluate the dimensional characteristics of the two candidate AFE pressure port configurations.

3.0 Test Article

The test articles consist of RCG coated cylinders (3.875" x 1.0 in thick) of FRCI-12, LI-2200, and LI-900 material. Pressure ports will be installed by both Langley and JSC. The models will be bonded to .160 in. strain isolation pad (SIP) and .032 in. aluminum. Figure 1 shows a typical model configuration.

4.0 Test Sequence/Conditions

All of the test specimens will be mounted in the standard 4.0 in diameter water cooled model holder that is available in the JSC 10 MW arc heated facility. Conical nozzles attached to the appropriate arc heater will be selected to achieve normal model surface temperature conditions from 2300°F to 2800°F and impact pressures from 20 to 40 psf.

a. Handle models with extreme care to avoid breakage of the quartz pressure port.

b. Prior to test and after test, dimensional measurements and color photographs will be taken of all test models.

c. Calibration tests will be conducted to establish the desired test temperature conditions by means of models with surface thermocouples. For the established test temperature conditions, impact pressure measurements should be taken.

d. Tentative test matrix:

Test Material	Peak Temperature	Test Duration
LI-900	2300°F	300 seconds
FRCI-12	2700°F	150 seconds
L1-2200	2800°F	150 seconds

LI-900 tests are intended to evaluate potential use of these pressure port concepts for Orbiter application. Number of tests at these high temperatures will be dependent upon performance.

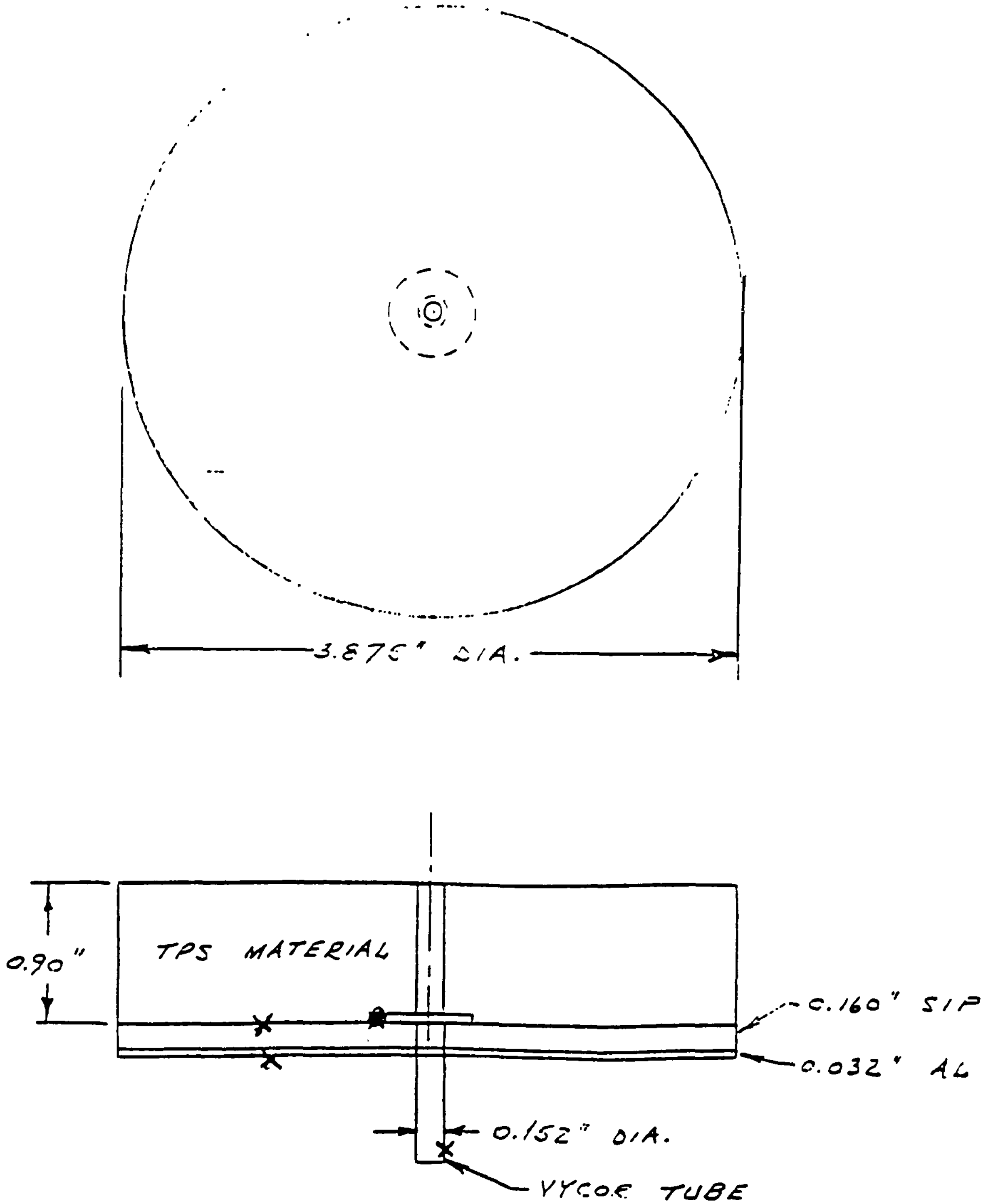
5.0 Documentation/Schedule

The test program will be conducted and documented in accordance with the established procedures required for development testing in the JSC 10 MW arc heated facility. After the necessary test conditions have been established by calibration tests, a test readiness review will be held. It is requested that these tests be implemented after completion of the on-going Orbiter ceramic gap filler test program.

D J Tillian

D. J. Tillian

Enclosure


3.875" DIA.
0.90"
TPS MATERIAL
0.160" SIP
0.032" AL
0.152" DIA.
VYCOR TUBE

X - CH-AL T/C 30 g

APPENDIX B

FACILITY DATA SUMMARY

NLE PRESSURE PORT CONFIGURATION EVALUATION

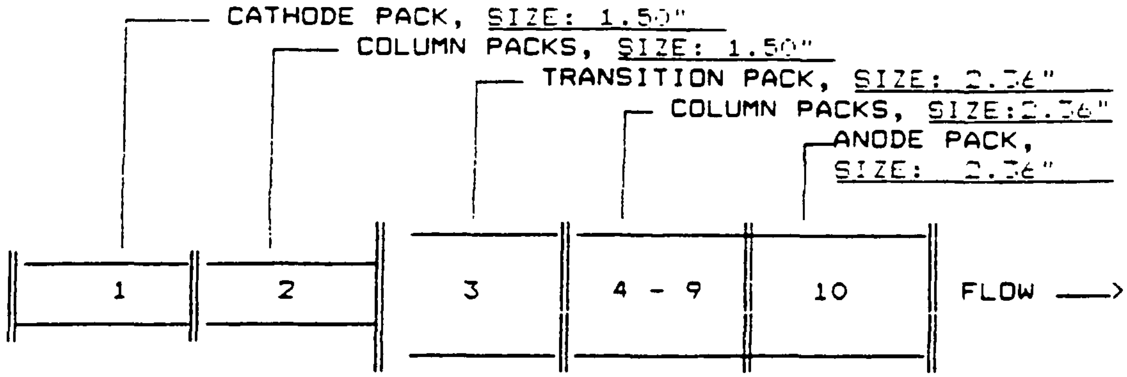
TEST MATRIX

RUN NO.	MASS FLOW, LB/SEC	ARC CURRENT, AMPS	ENTHALPY, BTU/LB	SURFACE PRESSURE PSF	SURFACE TEMPERATURE, DEG. F	Z DISTANCE, INCHES	NOTES
901	0.250	530	4,495	30	2,290	10	
	0.250	1,150	7,559	43	2,704	10	
	0.250	1,415	8,517	45	2,803	10	
	0.250	1,445	8,574	52	2,902	8	
	0.250	1,191	7,542	48	~2,800	8	

DUAL-DIAMETER
CONFIGURATION RECORD

TEST NO: 1-900-DD
NOZZLE:TYPE 15" CONICAL
MOUNTED INSIDE
WATER MANIFOLD: SINGLE PASS
INLET SET @ max PSI

DATE: 02-24-89
CATHODE: TUNGSTEN
COLUMN LENGTH 10 PACKS
TYPE PACKS: 1.25" -0-
1.50" 2
2.36" 8



COLUMN GAS INJECTION CONFIGURATION		
GAS	PACK	SEGMENTS
N2	1	2 . 4 . 6
N2	4	2 . 12
N2	5	2
N2	10	17 . 18 , 19
O2	6 / 7	2 . 8 . 12 . 18 / 2 , 8

PRESSURE TRANSDUCER LOCATIONS: N2 MANIFOLD ; PACK 1/SEG 10 ; PACK 5/SEG 8 ; PACK 10/SEG 16

6.0 OHM RIBBON WIRE BALLAST RESISTOR BETWEEN ANODE & 10" FLANGE

COMMENTS: EIGHT (8) 0.0625 DIA. ORIFICES IN ANODE PLENUM.

1.50" DIA TO 2.36" DIA TRANSITION AT SEGMENTS 4,5,& 6 IN PACK 3

REF: TPS FC-2210

REF: TPS

10 MW ARMSEF - TPI - 1989
AFE PRESSURE PORT CONFIGURATION EVALUATION

SETUP: 15" CONICAL NOZZLE WITH 10 PACK ARC HEATER

DATE	RUN NO.	TEST POINT	MASS FLOW, LB/SEC	CURRENT AMPS.	VOLTAGE, VOLTS.	ENTHALPY, BTU/LB	ANODE PRESS., PSIA	PITOT PRESS., PSF	SURFACE/VYCUR DEG F	RUN TIME, MIN.	REMARKS
03/08/89	900									2.9	ABORT, VOLTAGE TOO HIGH, WRONG GAS FLOW SETUP
03/09/89	901	5	0.250	531	3,141	4,495	12.51	30.24	2,290	22.4	2300 DEG. Z = 10"
		9	0.250	1,151	2,749	7,559	15.37	42.66	2,704		2400 DEG. Z = 10"
		13	0.250	1,415	2,648	8,517	16.12	45.45	2,803		2800 DEG. Z = 10"
		17	0.250	1,446	2,644	8,574	16.23	52.05	2,902		2900 DEG. Z = 8"
		22	0.250	1,191	2,752	7,542	15.65	47.83	~2,800		2800 DEG. Z = 8"
03/10/89	902									2.0	ABORT, ARMS NOT SET
03/10/89	903	5	0.246	511	3,156	4,408	12.26		2,321	13.1	2321 DEG., CAL MODEL 150 SEC. EXPOSURE AT ARM OUT, Z=10" 1st SEQUENCE, MODEL 157, LI-900
		12	0.247	511	3,160	4,399	12.37		114		
		14	0.247	511	3,156	4,389	12.35		142		
		15	0.247	508	3,164	4,368	12.40	26.78			
03/13/89	904	9	0.251	549	3,129	4,562	12.75		2,246	11.5	2246 DEG., CAL MODEL 150 SEC. EXPOSURE 2nd SEQUENCE, MODEL 162, LI-900, Z=10"
		14	0.251	550	3,130	4,577	12.75		107		
		17	0.252	549	3,134	4,544	12.74		173		
		18	0.251	551	3,135	4,585	12.62	35.72			
03/14/89	905	6	0.249	531	3,144	4,509	12.57		2,297	4.4	RUN TO VERIFY Z WAS 10" OR 8" FOR 2300 TEST POINT, Z=8"
		8	0.249	528	3,153	4,490	12.44	39.14			
03/14/89	906	4	0.250	531	3,153	4,479	12.45		2,276	7.7	REPEAT OF SEQ. 2, RUN 904, MODEL 162, Z=8", 150 SEC. EXPOSURE, 2300 POINT
		10	0.251	531	3,154	4,451	12.54		94		
		12	0.251	531	3,157	4,475	12.50		113		
		14	0.252	531	3,155	4,445	12.59	39.25			
03/14/89	907	5	0.251	1,236	2,718	7,869	15.51		2,697	9.3	2700 DEG. TEST POINT MODEL 159, SEQUENCE 3, 150 SEC. EXPOSURE Z=10"
		13	0.251	1,237	2,725	7,792	15.62		120		
		15	0.252	1,235	2,728	7,764	15.74		176		
		17	0.252	1,234	2,732	7,759	15.70	48.69			

L.P. MURRAY/LESC

10 MW ARMSEF - TP1 - 1089
AFE PRESSURE PORT CONFIGURATION EVALUATION

SETUP: 15" CONICAL NOZZLE WITH 10 PACK ARC HEATER

DATE	RUN NO.	TEST POINT	MASS FLOW, LB/SEC	CURRENT AMPS.	VOLTAGE, VOLTS.	ENTHALPY, BTU/LB	ANODE PRESS., PSIA	PITOT PRESS., PSF	SURFACE/ VYCOR DEG F	RUN TIME, MIN.	REMARKS
03/15/89	908	8	0.249	1,236	2,714	7,885	15.57	50.29		12.9	2700 DEG. TEST POINT MODEL 161, SEQUENCE 4, 150 SEC. EXPOSURE Z=10", V @ 0.90=2700
		12	0.250	1,236	2,716	7,835	15.63		111		
		14	0.249	1,235	2,718	7,852	15.60		167		
		16	0.248	1,236	2,715	7,809	15.54	49.97			
03/15/89	909	4	0.250	1,415	2,647	8,630	16.06		2,795	7.4	2800 DEG. TEST POINT MODEL 160, SEQUENCE 5, 150 SEC. EXPOSURE Z=10", V @ 0.90=2730
		6	0.249	1,417	2,647	8,612	16.10	51.76			
		10	0.250	1,417	2,648	8,506	16.09		137		
		13	0.250	1,417	2,651	8,505	16.12		278		
		14	0.249	1,418	2,651	8,530	16.16	51.56			
03/16/89	910	3	0.246	1,417	2,625	8,628	15.85	50.79		8.2	2800 DEG. TEST POINT MODEL 164, SEQUENCE 6, 150 SEC. EXPOSURE Z=10", V @ 0.90=2720
		7	0.250	1,416	2,634	8,433	15.97		106		
		10	0.250	1,415	2,638	8,431	15.99		149		
		11	0.250	1,415	2,640	8,397	16.03	50.06			
03/16/89	911	5	0.250	1,452	2,637	8,741	16.27		2,922	7.8	2900 DEG. TEST POINT MODEL 163, SEQUENCE 8, 150 SEC. EXPOSURE Z=8", V @ 0.90=2790
		7	0.251	1,452	2,639	8,696	16.30	57.90			
		11	0.252	1,451	2,641	8,556	16.27		126		
		14	0.253	1,452	2,641	8,519	16.26		203		
		15	0.251	1,451	2,642	8,562	16.30	57.69			
03/17/89	912	4	0.249	1,452	2,621	8,836	16.08	59.56		6.1	2900 DEG. TEST POINT MODEL 158, SEQUENCE 7, 150 SEC. EXPOSURE Z=8", V @ 0.90=2830
		8	0.249	1,450	2,622	8,702	16.02		156		
		11	0.251	1,451	2,625	8,642	16.09		254		
		12	0.250	1,452	2,628	8,659	16.05	59.30			
03/17/89	913	3	0.250	534	3,155	4,563	12.49	40.63		5.2	2300 DEG. TEST POINT MODEL 157, REPEAT OF SEQUENCE 1, 150 SEC. EXPOSURE, Z=8", V @ 0.90=2728
		7	0.250	531	3,154	4,500	12.47		96		
		10	0.250	530	3,157	4,497	12.48		125		
		11	0.251	528	3,163	4,458	12.57	40.58			
03/22/89	914	5	0.248	1,452	2,629	9,049	16.03	59.65		6.1	REPEAT RUN ON -158 WITH VITON TUBING REMOVED, SPECIAL SLUG CALORIMETER IN-STALLED IN CAVITY
		9	0.250	1,452	2,635	8,659	16.16		2,809		
		12	0.250	1,453	2,638	8,870	16.22		2,815		
		13	0.250	1,453	2,640	8,824	16.15	59.23			

L.P. MURRAY/LESC

10 MW ARMSEF - TP1 - 1989
AFE PRESSURE PORT CONFIGURATION EVALUATION

SETUP: 15° CONICAL NOZZLE WITH 10 PACK ARC HEATER

DATE	RUN NO.	TEST POINT	MASS FLOW, LB/SEC	CURRENT AMPS.	VOLTAGE, VOLTS.	ENTHALPY, BTU/LB	ANODE PRESS., PSIA	PITOT PRESS., PSF	SURFACE/ VYCOR, DEG F	RUN TIME, MIN.	REMARKS
03/22/89	915	3	0.250	1,237	2,729	8,137	15.59	49.80		7.0	REPEAT RUN AT 2700 DEG. ON -164 WITH DAMAGE AROUND PORT 150 SEC. EXPOSURE
		7	0.250	1,237	2,732	8,109	15.72		166		
		10	0.251	1,235	2,735	8,014	15.77		323		
		11	0.252	1,236	2,734	7,971	15.82	49.08			
03/22/89	916	3	0.251	1,453	2,649	9,011	16.27	60.28		5.7	REPEAT RUN AT 2900 DEG. ON -163 WITH VITON TUBING OFF AND SLUG CALORIMETER IN-STALLED IN CAVITY
		7	0.251	1,452	2,656	8,061	16.34		2,031		
		10	0.250	1,452	2,661	8,889	16.34		2,028		
		11	0.253	1,451	2,650	8,767	16.42	60.31			

ORIGINAL PAGE IS OF POOR QUALITY

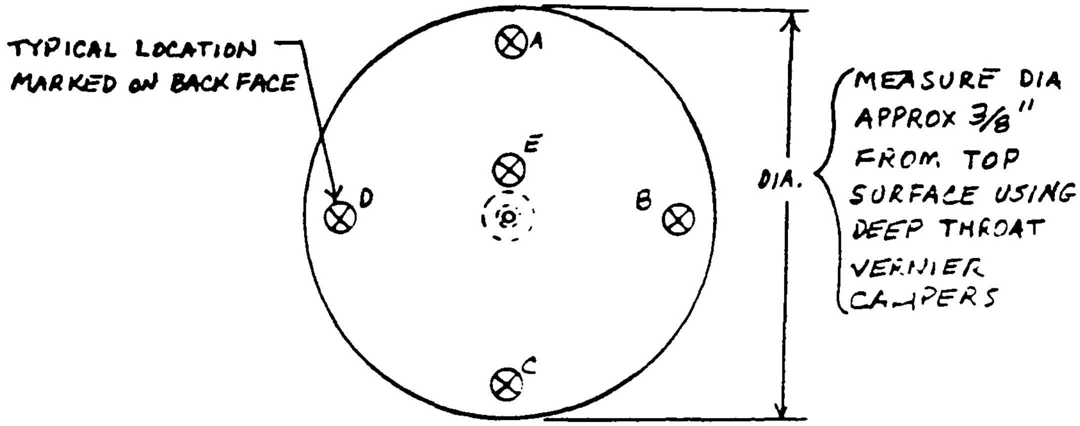
10 MW ARMSEF DATA - TP1 - 1988
TEMPERATURE DATA

RUN NO.	SEQUENCE NO.	ARC CURRENT, AMPS	SURFACE PRESS., PSF	MODEL NO.	TARGET SURFACE TEMP DEG F	ACTUAL SURFACE TEM DEG F	T/C #8, MAX. TEMP., DEG F	NOTES/COMMENTS
903	1	511	26.78	1-L9FB-157	2,300	2,321	254	
904 906	2	550	35.72	6-L9-162	2,300	2,246	267	
907	3	1,235	48.69	3-F12FB-159	2,700	2,697	266	
908	4	1,235	49.97	5-F12-161	2,700	~2,700	297	
909	5	1,418	51.56	4-F12FB-160	2,800	2,795	351	
910	6	1,415	50.83	8-F12-164	2,800	~2,800		
	7			2-L22FB-158	2,900			
	8			7-L22-163	2,900			

APPENDIX C

SURFACE VARIATION DATA

AFE PRESSURE PORT THERMAL PERFORMANCE TESTS



VIEW FROM TOP OF MODEL

EESL MODEL I.D. 162 MAT'L LI 900
ALSO MARKED LI 900 #6

PRE-TEST		POST-TEST	
A	1.113	A	1.110
B	1.105	B	1.110
C	1.112	C	1.108
D	1.113	D	1.105
E	1.117	E	1.106
DIA.	3.873	DIA.	3.874

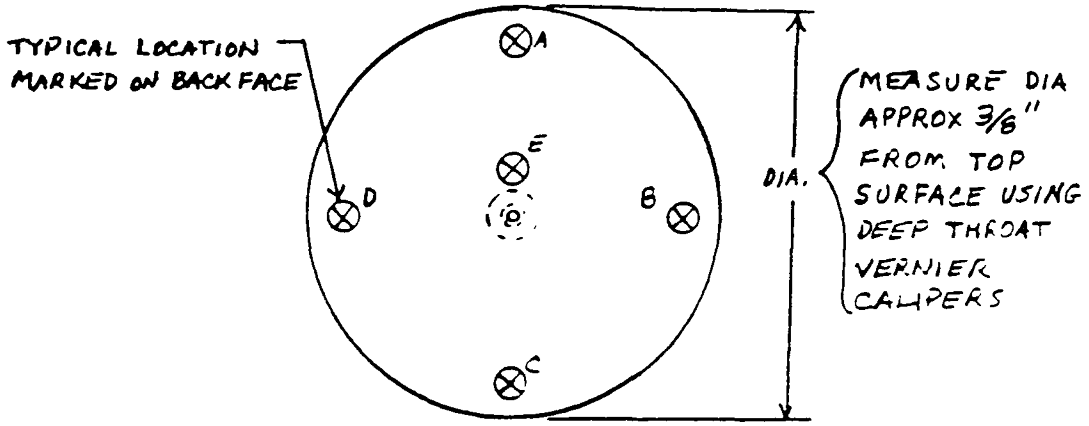
TECH INIT: [illegible]
DATE [illegible]
QA STAMP

WEIGHT ______
TECH INIT: ______
DATE ______
QA STAMP

WEIGHT ~~______~~ 1.96 [illegible]
TEST RUN # ______ DATE 3 1989
TECH INIT: [illegible]
DATE [illegible]
QA STAMP

NOTE: WEIGHTS TO INCLUDE T/C'S WITH WIRE ENDS STRIPPED, BUT WITHOUT T/C CONNECTORS ATTACHED

AFE PRESSURE PORT THERMAL PERFORMANCE TESTS



VIEW FROM TOP OF MODEL

EESL MODEL I.D. 159 MAT'L FRCI 12
ALSO MARKED FRCI 12 #3

PRE-TEST		POST-TEST	
A	1.102	A	1.100
B	1.104	B	1.104
C	1.102	C	1.088
D	1.104	D	1.100
E	1.106	E	1.102
DIA.	3.872	DIA.	3.873

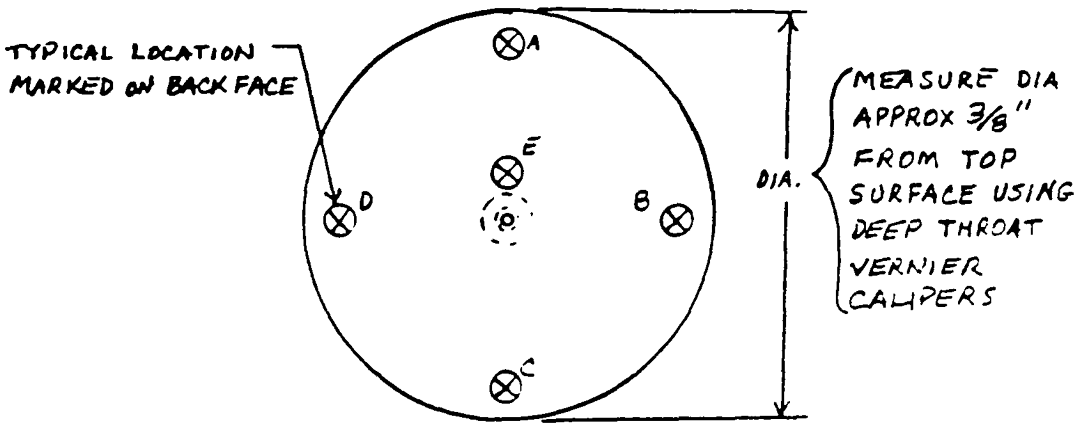
TECH INIT: BS
DATE 2.7.89
QA STAMP

WEIGHT ______
TECH INIT: ______
DATE ______
QA STAMP

WEIGHT 1.907 [illegible]
TEST RUN # [illegible] DATE 3-14-89
TECH INIT: BS
DATE [illegible]
QA STAMP

NOTE: WEIGHTS TO INCLUDE T/C'S WITH WIRE ENDS STRIPPED, BUT WITHOUT T/C CONNECTORS ATTACHED

AFE PRESSURE PORT THERMAL PERFORMANCE TESTS



VIEW FROM TOP OF MODEL

EESL MODEL I.D. 161 MAT'L FRCI 12
ALSO MARKED FRCI 12 #5

PRE-TEST		POST-TEST	
A	1.107	A	1.103
B	1.104	B	1.098
C	1.103	C	1.100
D	1.109	D	1.104
E	1.106	E	1.099
DIA.	3.875	DIA.	3.868

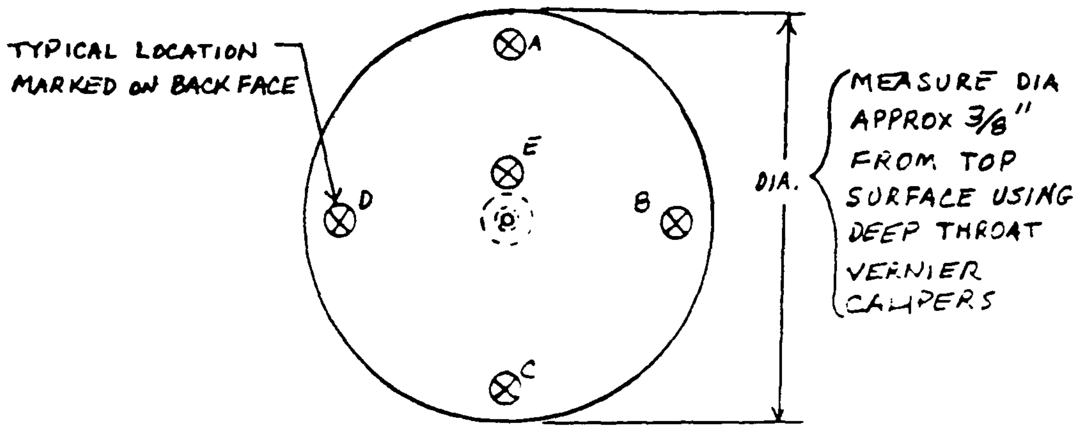
TECH INIT: [illegible]
DATE [illegible]
QA STAMP

WEIGHT ______
TECH INIT: ______
DATE ______
QA STAMP

WEIGHT 1.908
TEST RUN # ______ DATE 3-15-89
TECH INIT: [illegible]
DATE [illegible]
QA STAMP

NOTE: WEIGHTS TO INCLUDE T/C'S WITH WIRE ENDS STRIPPED, BUT WITHOUT T/C CONNECTORS ATTACHED

AFE PRESSURE PORT THERMAL PERFORMANCE TESTS



VIEW FROM TOP OF MODEL

EESL MODEL I.D. 166 MAT'L FRCI 12
ALSO MARKED FRCI 12 #4

PRE-TEST		POST-TEST	
A	1.087	A	1.078
B	1.086	B	1.076
C	1.092	C	1.066
D	1.085	D	1.063
E	1.086	E	1.070
DIA.	~~3.88~~ 3.877 KCR	DIA.	3.874

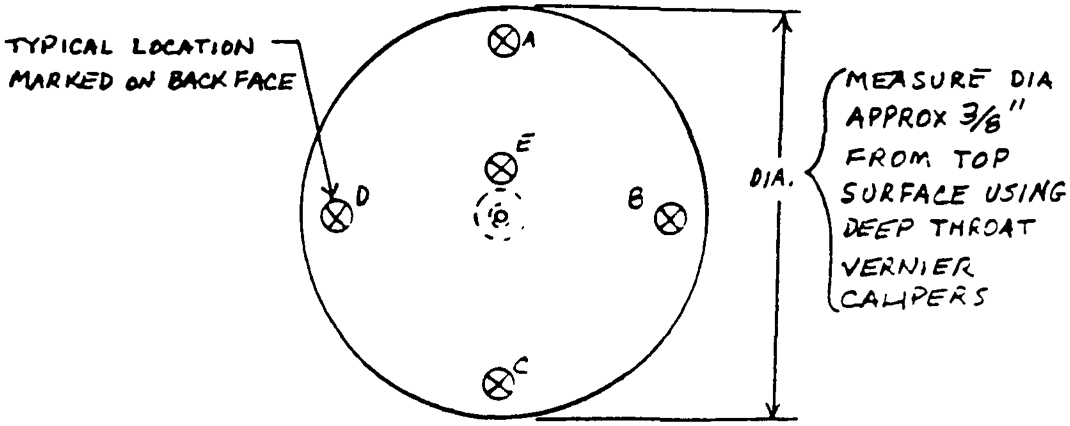
TECH INIT: [illegible]
DATE [illegible]
QA STAMP [illegible]

WEIGHT ______
TECH INIT: ______
DATE ______
QA STAMP

WEIGHT 1.969.00
TEST RUN # [illegible] DATE 3-15-89
TECH INIT: [illegible]
DATE [illegible]
QA STAMP

NOTE: WEIGHTS TO INCLUDE T/C'S WITH WIRE ENDS STRIPPED, BUT WITHOUT T/C CONNECTORS ATTACHED

AFE PRESSURE PORT THERMAL PERFORMANCE TESTS



VIEW FROM TOP OF MODEL

EESL MODEL I.D. 164   MAT'L FRCI 12
ALSO MARKED FRCI 12 #8

PRE-TEST		POST-TEST	
A	1.117	A	1.108
B	1.123	B	1.109
C	1.109	C	1.109
D	1.111	D	1.111
E	1.124	E	1.111
DIA.	3.875	DIA.	3.870

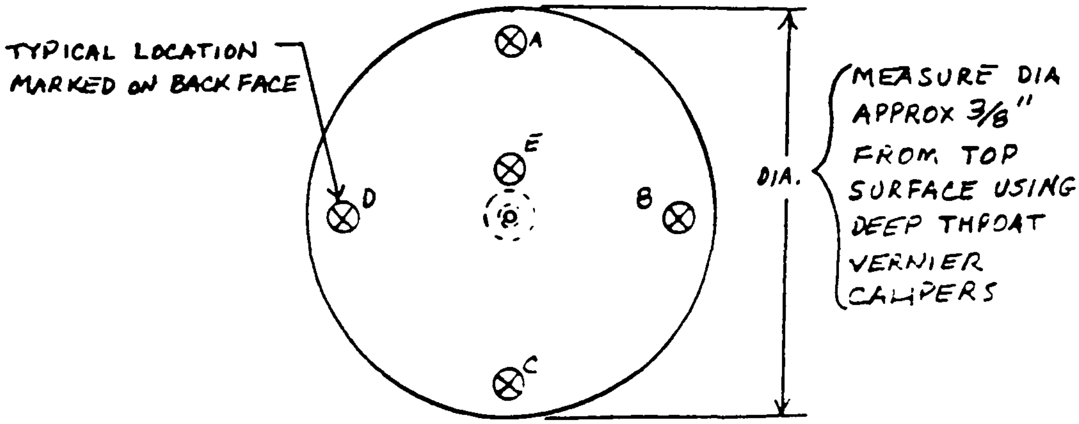
TECH INIT: [illegible]
DATE [illegible]
QA STAMP

WEIGHT ______
TECH INIT: ______
DATE ______
QA STAMP

WEIGHT
TEST RUN # 1.916.DD DATE 3-16-89
TECH INIT: [illegible]
DATE 3/20/89
QA STAMP

NOTE: WEIGHTS TO INCLUDE T/C'S WITH WIRE ENDS STRIPPED, BUT WITHOUT T/C CONNECTORS ATTACHED

AFE PRESSURE PORT THERMAL PERFORMANCE TESTS



VIEW FROM TOP OF MODEL

EESL MODEL I.D. 163 MAT'L LI 2200
ALSO MARKED LI 2200 #7

PRE-TEST		POST-TEST	
A	1.110	A	1.106
B	1.114	B	1.103
C	1.101	C	1.098
D	1.113	D	1.110
E	1.115	E	1.112
DIA.	3.875	DIA.	3.868

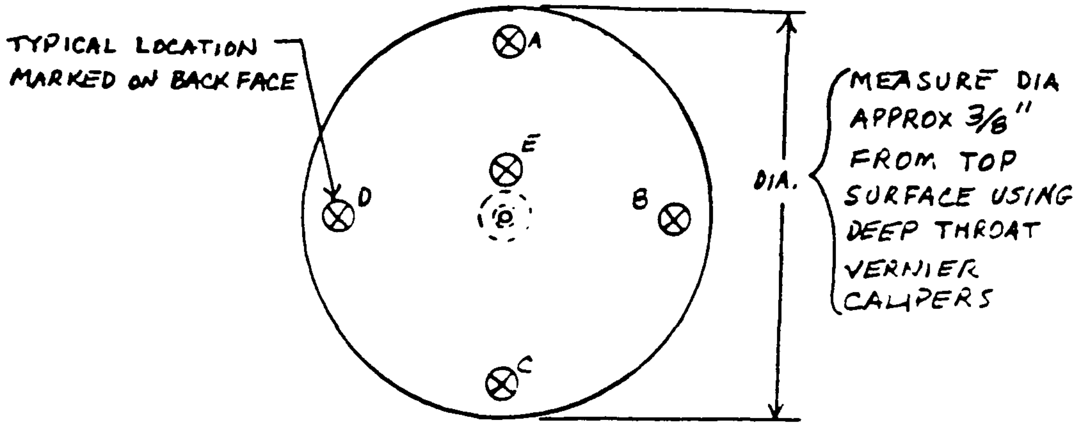
TECH INIT: [illegible]
DATE [illegible]
QA STAMP

WEIGHT ______
TECH INIT: ______
DATE ______
QA STAMP

WEIGHT \\\
TEST RUN # 1.9 [illegible] DATE 3-16-89
TECH INIT: [illegible]
DATE 3/20/89
QA STAMP

NOTE: WEIGHTS TO INCLUDE T/C'S WITH WIRE ENDS STRIPPED, BUT WITHOUT T/C CONNECTORS ATTACHED

AFE PRESSURE PORT THERMAL PERFORMANCE TESTS



VIEW FROM TOP OF MODEL

EESL MODEL I.D. 158 MAT'L LI 2200
ALSO MARKED 2200 #2

PRE-TEST		POST-TEST	
A	~~3.877~~ 1.098	A	
B	1.112	B	
C	1.094	C	
D	1.087	D	
E	1.101	E	
DIA.	3.877	DIA.	

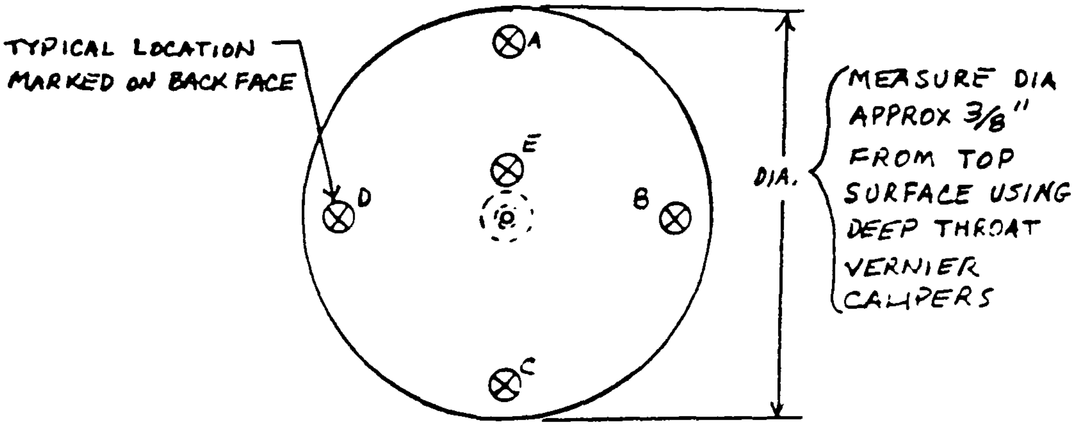
TECH INIT: DS
DATE 2-3-89
QA STAMP

WEIGHT ______
TECH INIT: ______
DATE ______
QA STAMP

WEIGHT ______
TEST RUN # 1-912-DD DATE 3-17-89
TECH INIT: ______
DATE ______
QA STAMP

NOTE: WEIGHTS TO INCLUDE T/C'S WITH WIRE ENDS STRIPPED, BUT WITHOUT T/C CONNECTORS ATTACHED

AFE PRESSURE PORT THERMAL PERFORMANCE TESTS



VIEW FROM TOP OF MODEL

EESL MODEL I.D. 157 MAT'L LI 900
ALSO MARKED 900 #1

PRE-TEST		POST-TEST	
A	1.109	A	1.102
B	1.119	B	1.115
C	1.111	C	1.09
D	1.114	D	1.116
E	1.110	E	.098
DIA.	3.872	DIA.	~~3.186~~ 3.862

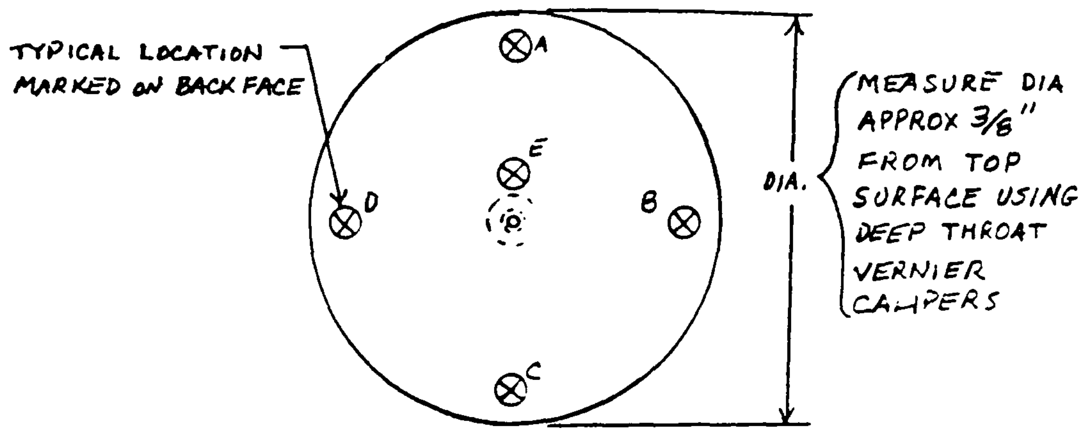
TECH INIT: BJ
DATE 3/7/89
QA STAMP

WEIGHT 12.354
TECH INIT: BJ
DATE 3/9/89
QA STAMP

WEIGHT 11.913 DATE 3-10-89
TEST RUN #
TECH INIT: BJ
DATE 3/16/89
QA STAMP

NOTE: WEIGHTS TO INCLUDE T/C'S WITH WIRE ENDS STRIPPED, BUT WITHOUT T/C CONNECTORS ATTACHED

AFE PRESSURE PORT THERMAL PERFORMANCE TESTS



VIEW FROM TOP OF MODEL

EESL MODEL I.D. 158 MAT'L LI 2200
ALSO MARKED 2200 #2

PRE-TEST		POST-TEST	
A	1.098	A	1.084
B	1.112	B	1.000
C	1.094	C	1.076
D	1.087	D	1.076
E	1.101	E	1.094
DIA.	3.877	DIA.	3.860

TECH INIT: BJ
DATE 3/17/89
QA STAMP

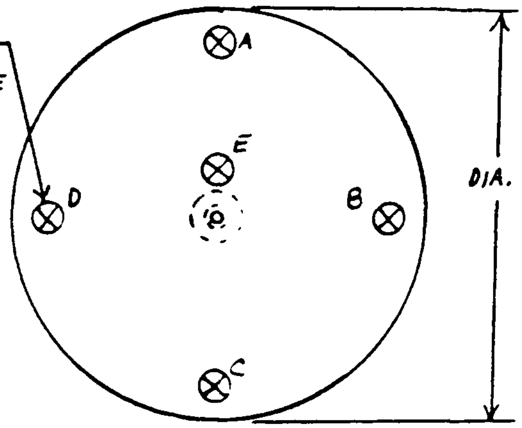
WEIGHT
TEST RUN # 714 DATE 3-22-89
TECH INIT: BJ
DATE 3/22/89
QA STAMP

WEIGHT ______
TECH INIT: ______
DATE ______
QA STAMP

NOTE: WEIGHTS TO INCLUDE T/C'S WITH WIRE ENDS STRIPPED, BUT WITHOUT T/C CONNECTORS ATTACHED

AFE PRESSURE PORT THERMAL PERFORMANCE TESTS

TYPICAL LOCATION MARKED ON BACK FACE



MEASURE DIA APPROX 3/8" FROM TOP SURFACE USING DEEP THROAT VERNIER CALIPERS

VIEW FROM TOP OF MODEL

EESL MODEL I.D. 164 MAT'L FRCI 12
ALSO MARKED FRCI 12 #8

PRE-TEST		POST-TEST	
A	1.117	A	1.105
B	1.123	B	1.112
C	1.109	C	1.104
D	1.111	D	1.112
E	1.124	E	1.109
DIA.	3.875	DIA.	3.872

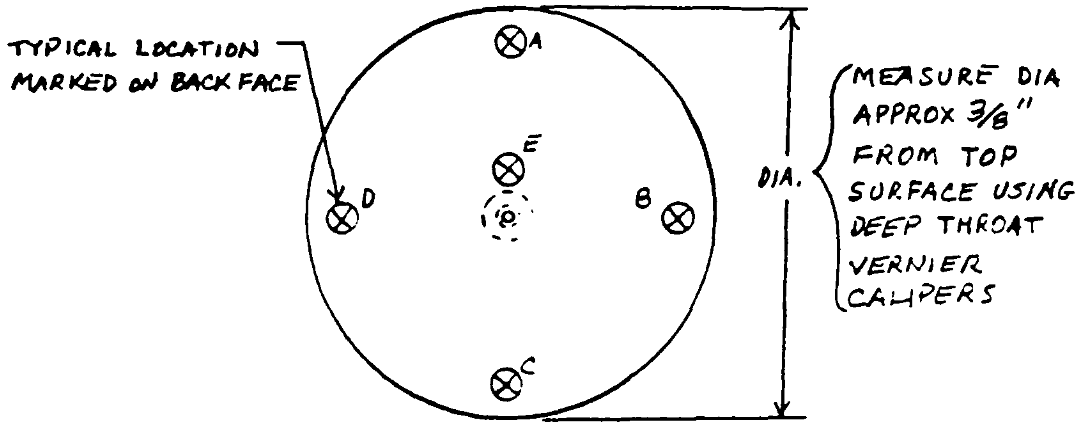
TECH INIT: BJ.
DATE 3/22/89
QA STAMP

WEIGHT ______
TECH INIT: ______
DATE ______
QA STAMP

WEIGHT \\\
TEST RUN # 915 DATE 3-23-89
TECH INIT: BJ.
DATE 3/24/89
QA STAMP

NOTE: WEIGHTS TO INCLUDE T/C'S WITH WIRE ENDS STRIPPED, BUT WITHOUT T/C CONNECTORS ATTACHED

AFE PRESSURE PORT THERMAL PERFORMANCE TESTS



VIEW FROM TOP OF MODEL

EESL MODEL I.D. 163 MAT'L LI2200
ALSO MARKED LI2200 #7

PRE-TEST		POST-TEST	
A	1.110	A	1.076
B	1.114	B	1.082
C	1.101	C	1.068
D	1.113	D	1.085
E	1.115	E	1.093
DIA.	3.875	DIA.	3.880

TECH INIT: EL
DATE 3/22/89
QA STAMP

WEIGHT ______
TECH INIT: ______
DATE ______
QA STAMP

WEIGHT \\\\\\
TEST RUN # 916 DATE 3 22 89
TECH INIT: EL
DATE 3/22/89
QA STAMP

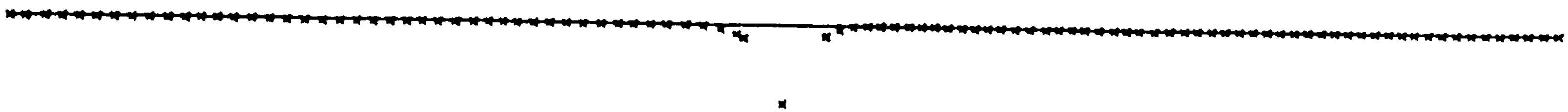
NOTE: WEIGHTS TO INCLUDE T/C'S WITH WIRE ENDS STRIPPED, BUT WITHOUT T/C CONNECTORS ATTACHED

APPENDIX D

SURFACE PROFILES

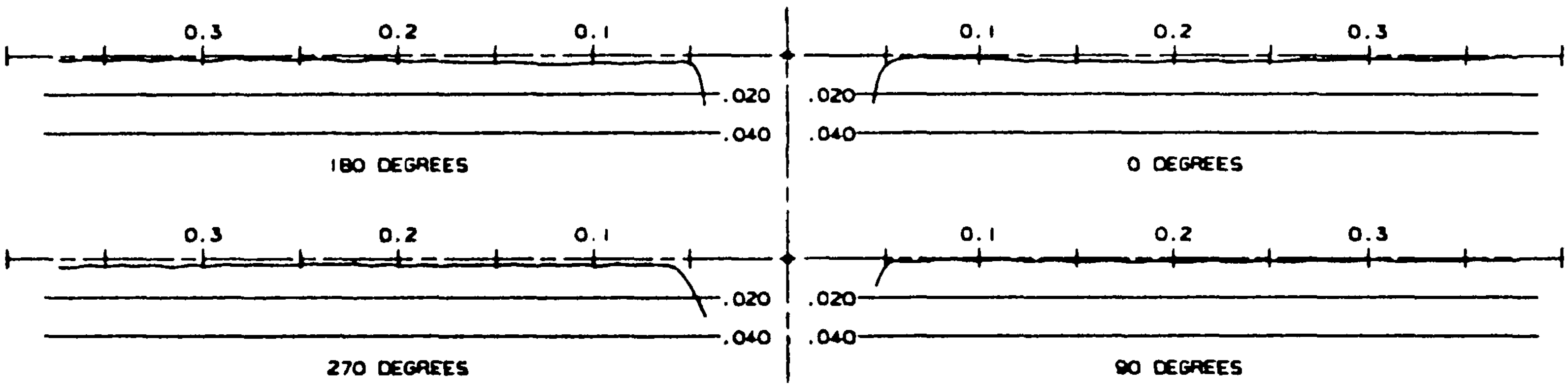
ANVIL-5000 REL/REV 1.1.7 BY MCS

PRETEST SPECIMEN



TYPICAL FOR ALL SPECIMEN

SPECIMEN #1

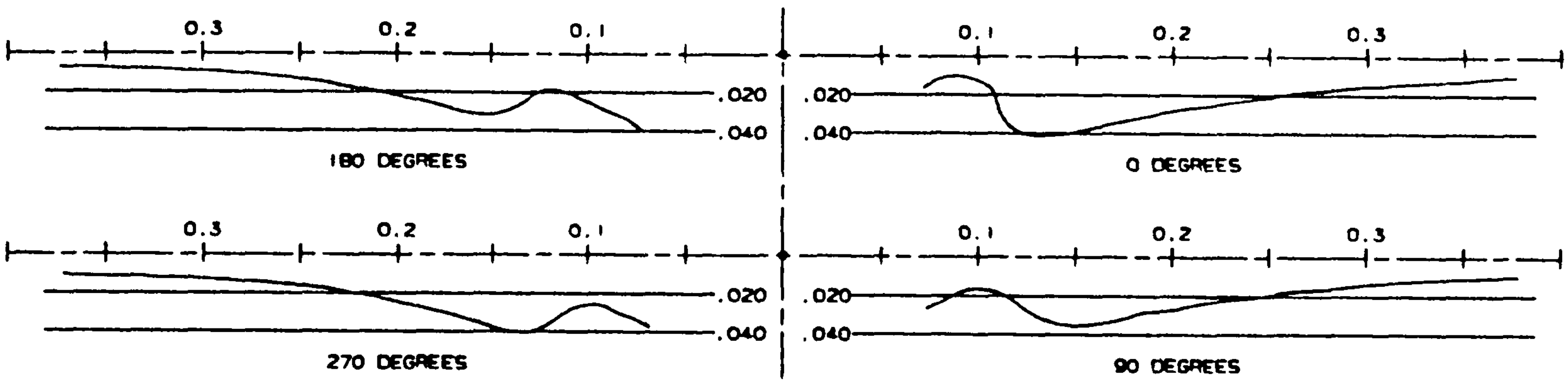


RUN 913

T/A 1-L9FB-157

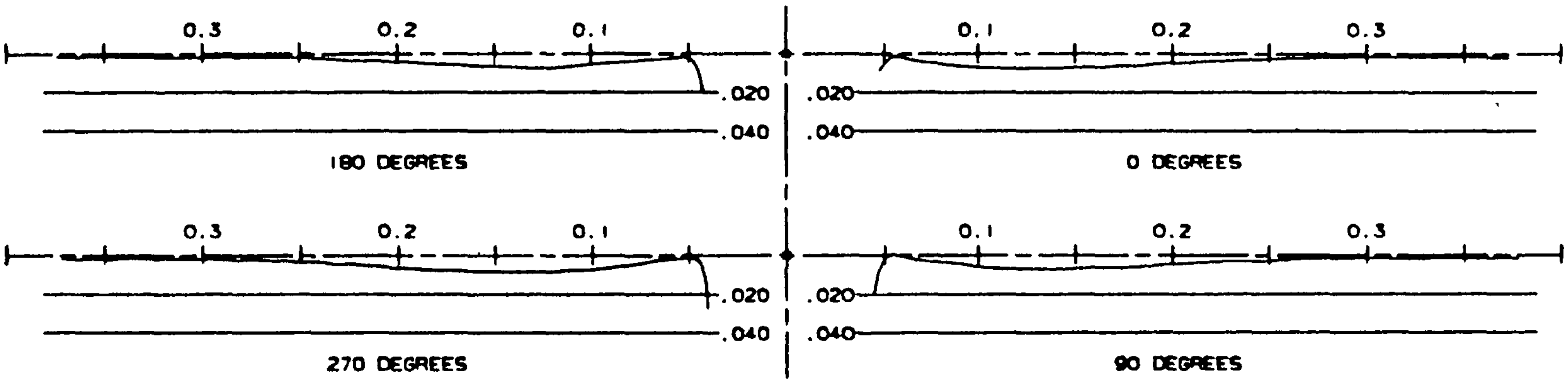
ANALYSIS

SPECIMEN #2



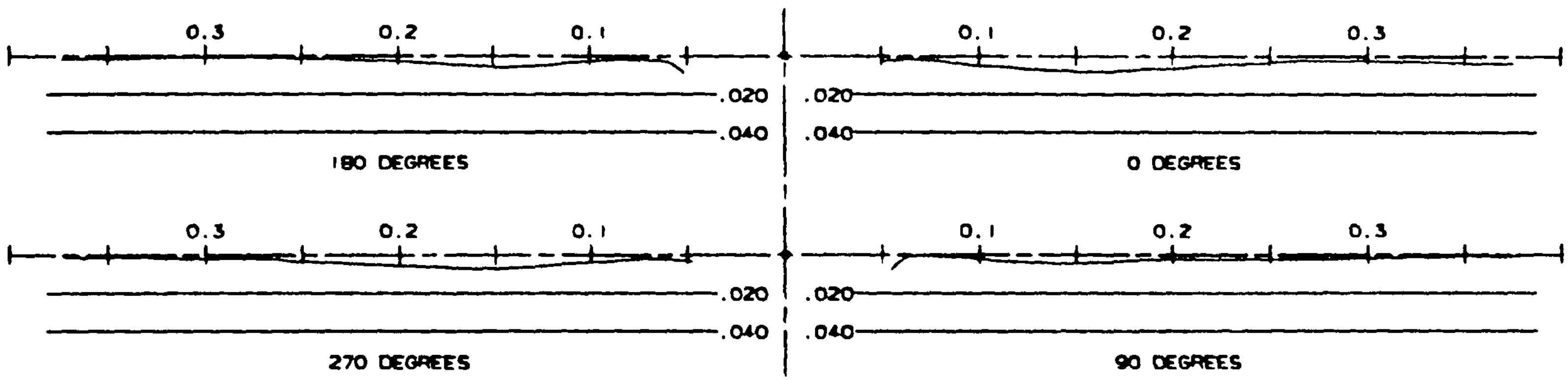
RUN 914
T/A 2-L22FB-158

SPECIMEN #3



RUN 907
T/A 3-F12FB-159

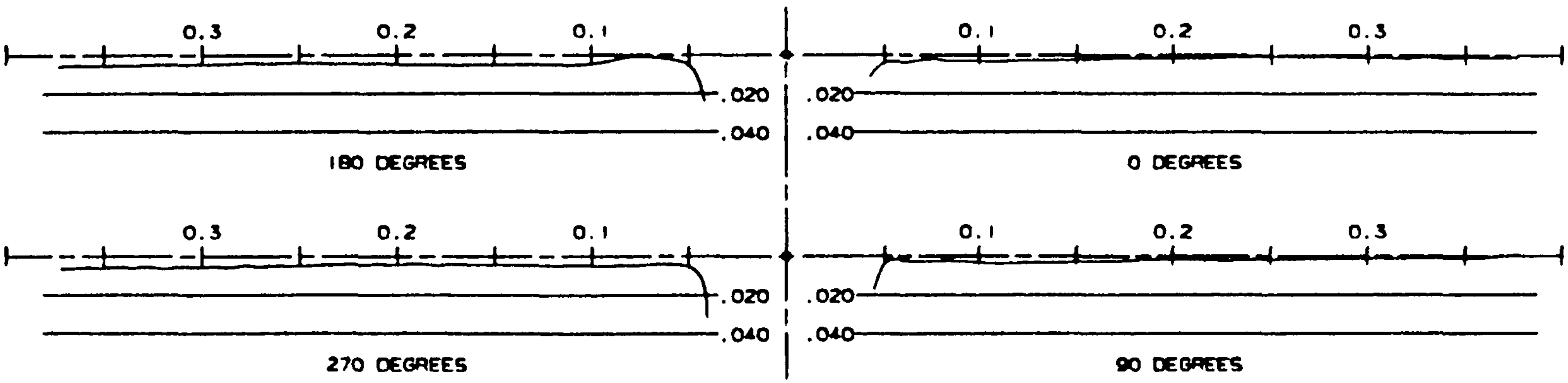
SPECIMEN #4



RUN 909

T/A 4-F12FB-160

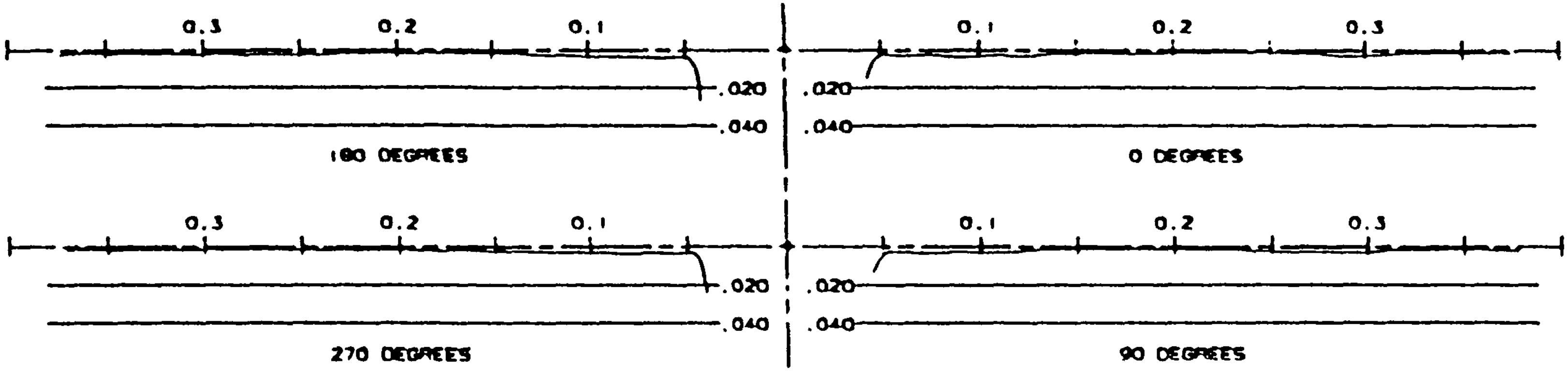
SPECIMEN #5



RUN 908
T/A 5-F12-161

D-7

SPECIMEN #6

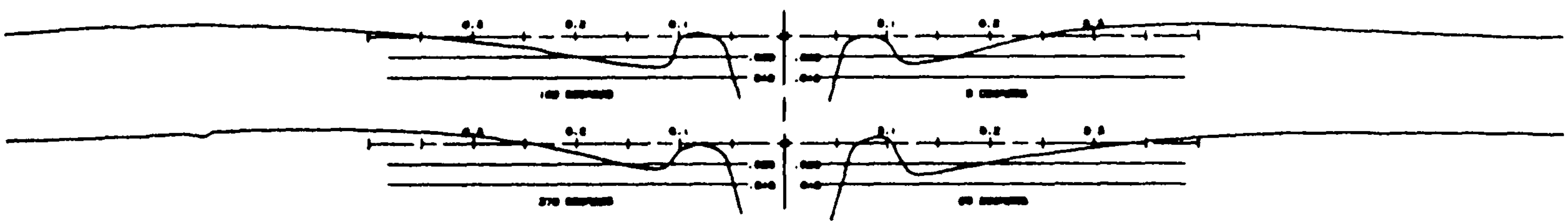


RUN 906

T/A 6-L9-162

ANALYSIS

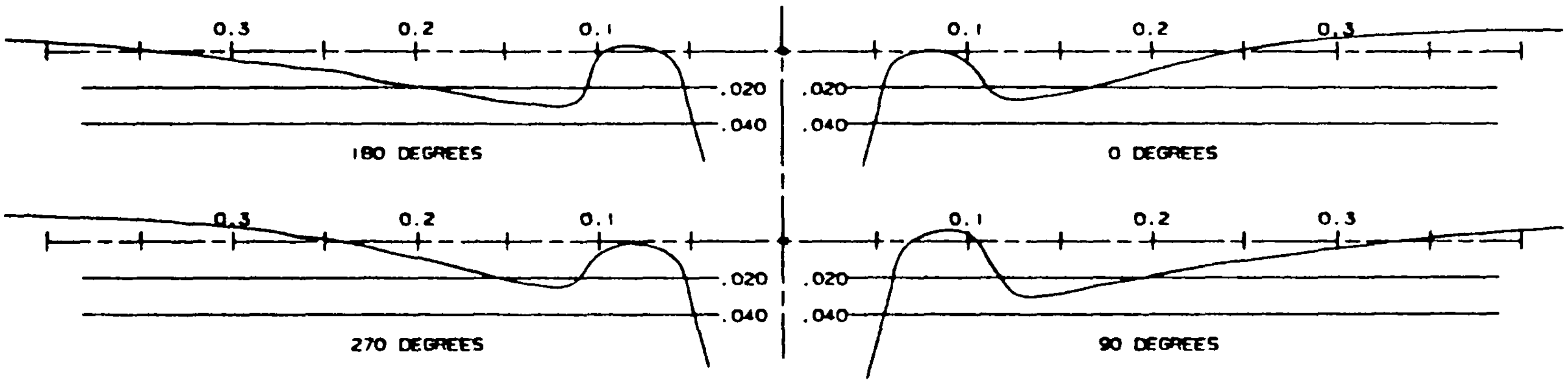
SPECIMEN #7



RUN 916
T/A 7-L22-163

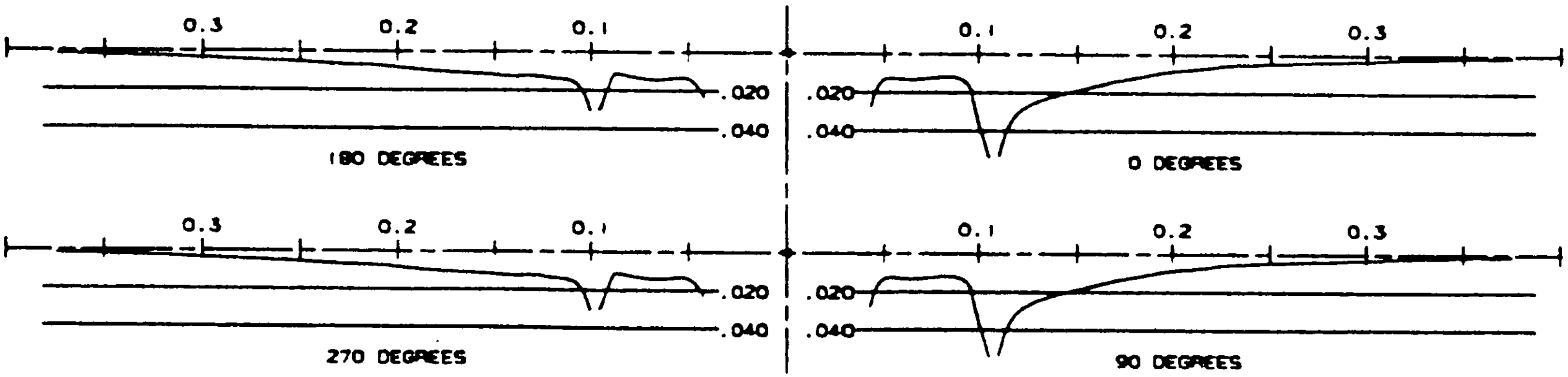
ANALYSIS

SPECIMEN #7



CLOSE-UP
RUN 916
T/A 7-L22-163

SPECIMEN #8



CLOSE-UP
RUN 915
T/A 8-F12-164

APPENDIX E

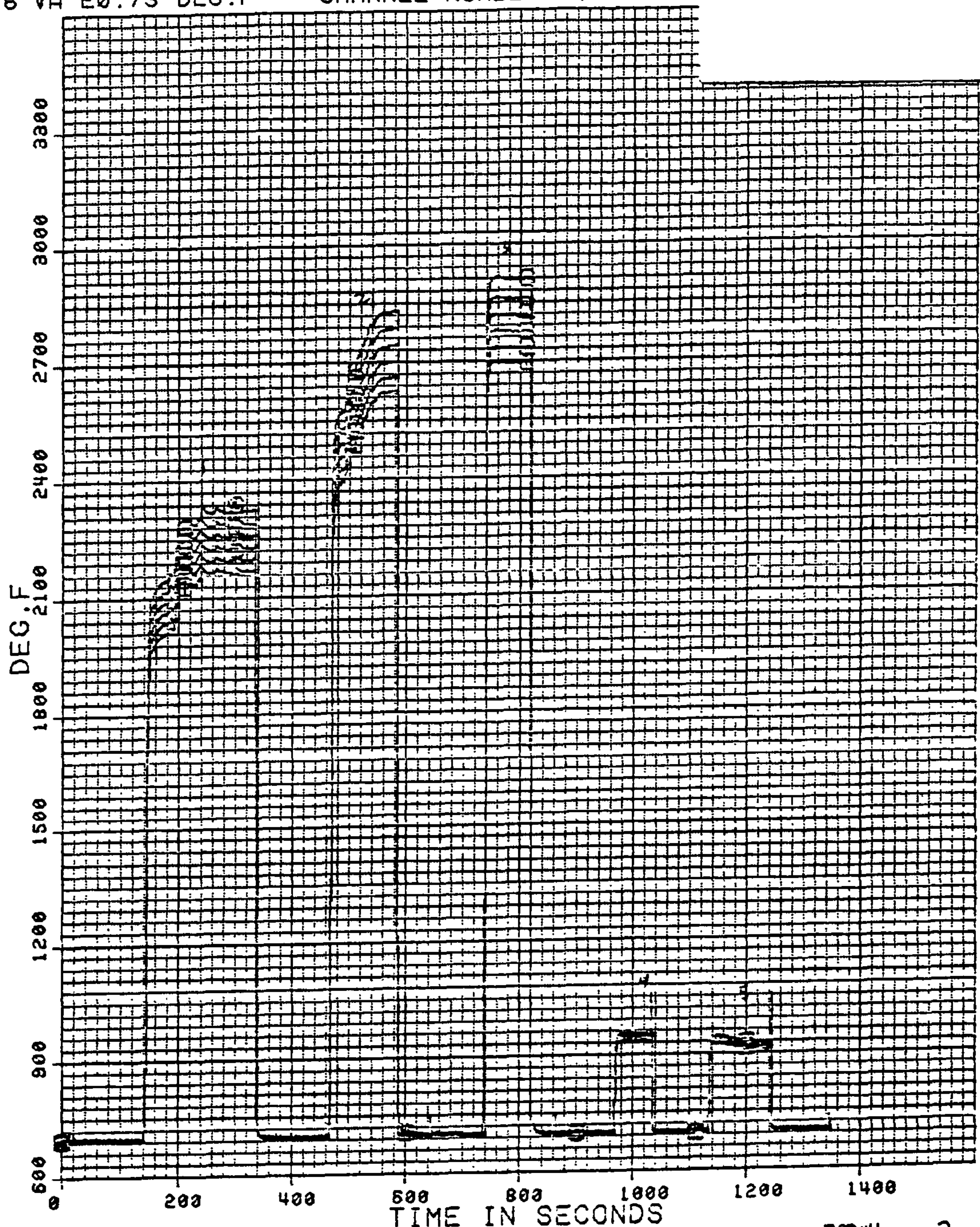
PYROMETER DATA

T93

1-901-DD
DATE = 3/ 9/89 AVERAGE INTERVAL 1.0 SEC TIME = 18:58:21.0 TO 19:20:50.0
PROCESSING DATE 03/10/89

1 VAN E1.0 DEG.F CHANNEL NUMBER 85
2 VA E0.95 DEG.F CHANNEL NUMBER 86
3 VA E0.90 DEG.F CHANNEL NUMBER 87
4 VA E0.85 DEG.F CHANNEL NUMBER 88
5 VA E0.80 DEG.F CHANNEL NUMBER 89
6 VA E0.75 DEG.F CHANNEL NUMBER 90

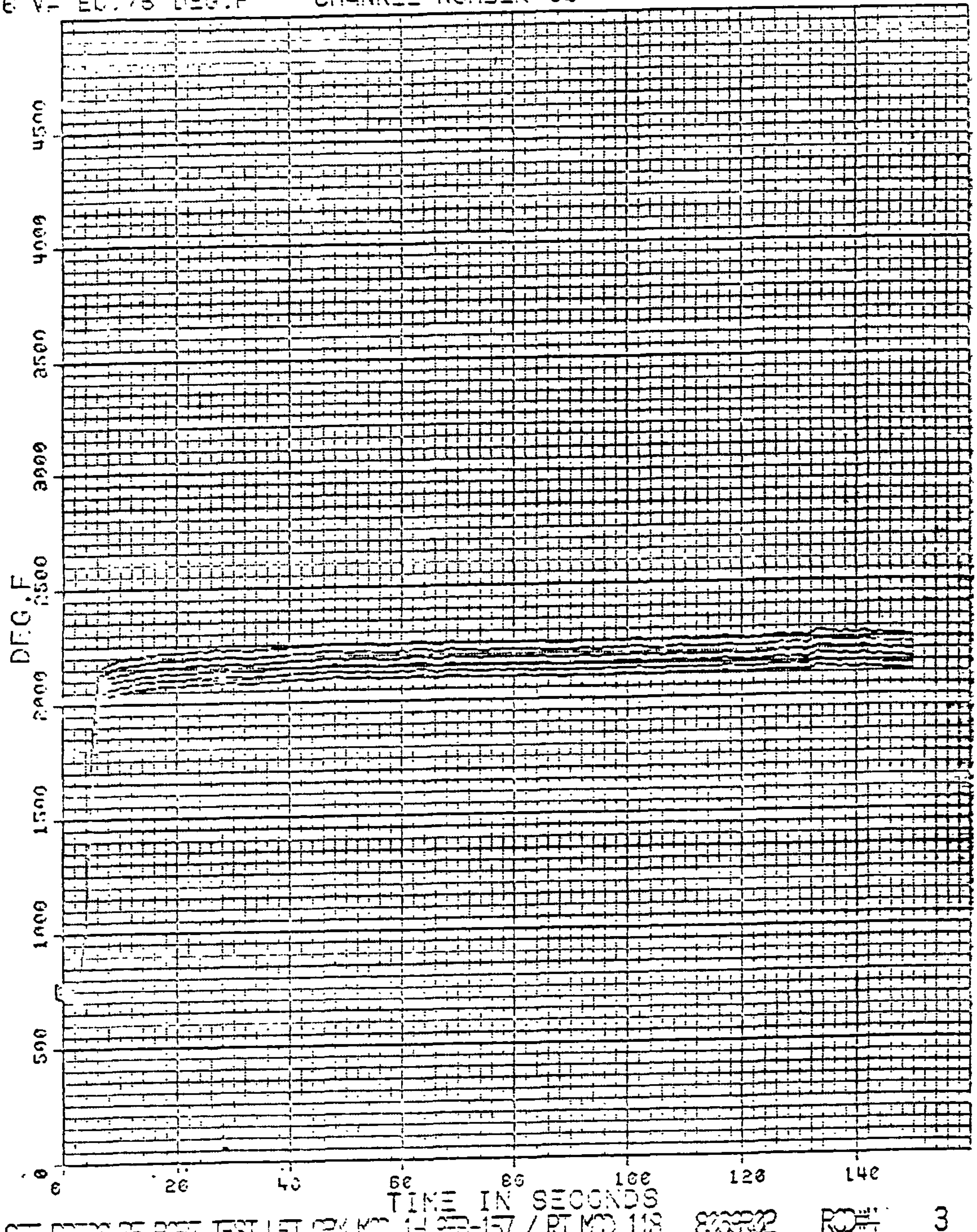
CAL RUN
901



AFE PRESSURE PORT CAL TEST RIGHT ARM MODEL # 117 _8068R01 ROD#4 2

1-616 ...
DATE = 8/23/88 AVERAGE INTERVAL 1.0 SEC TIME = 23: 8:21.0 TO 23:10:52.0
PROCESSING DATE 09/10/88

1 VEN E1.0 DEG.F CHANNEL NUMBER 85
2 VP E3.9 DEG.F CHANNEL NUMBER 86
3 VP E3.9 DEG.F CHANNEL NUMBER 87
4 VP E2.95 DEG.F CHANNEL NUMBER 88
5 VP E2.8 DEG.F CHANNEL NUMBER 89
6 VP E0.75 DEG.F CHANNEL NUMBER 90



AFE PRESSURE PORT TEST LFT ARM MOD 1-L6B-157 / RT MOD 118 8068R02 ROD# 3

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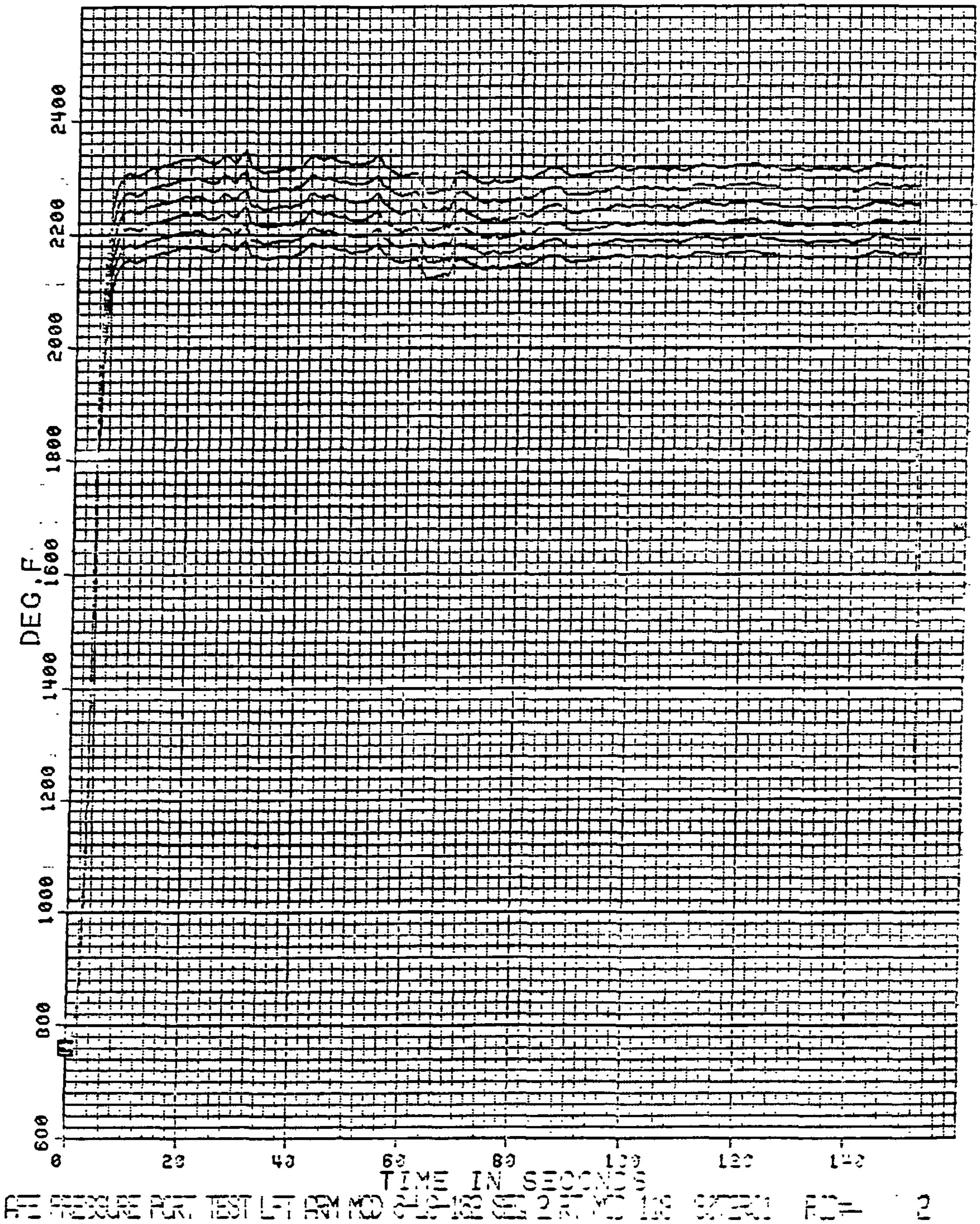
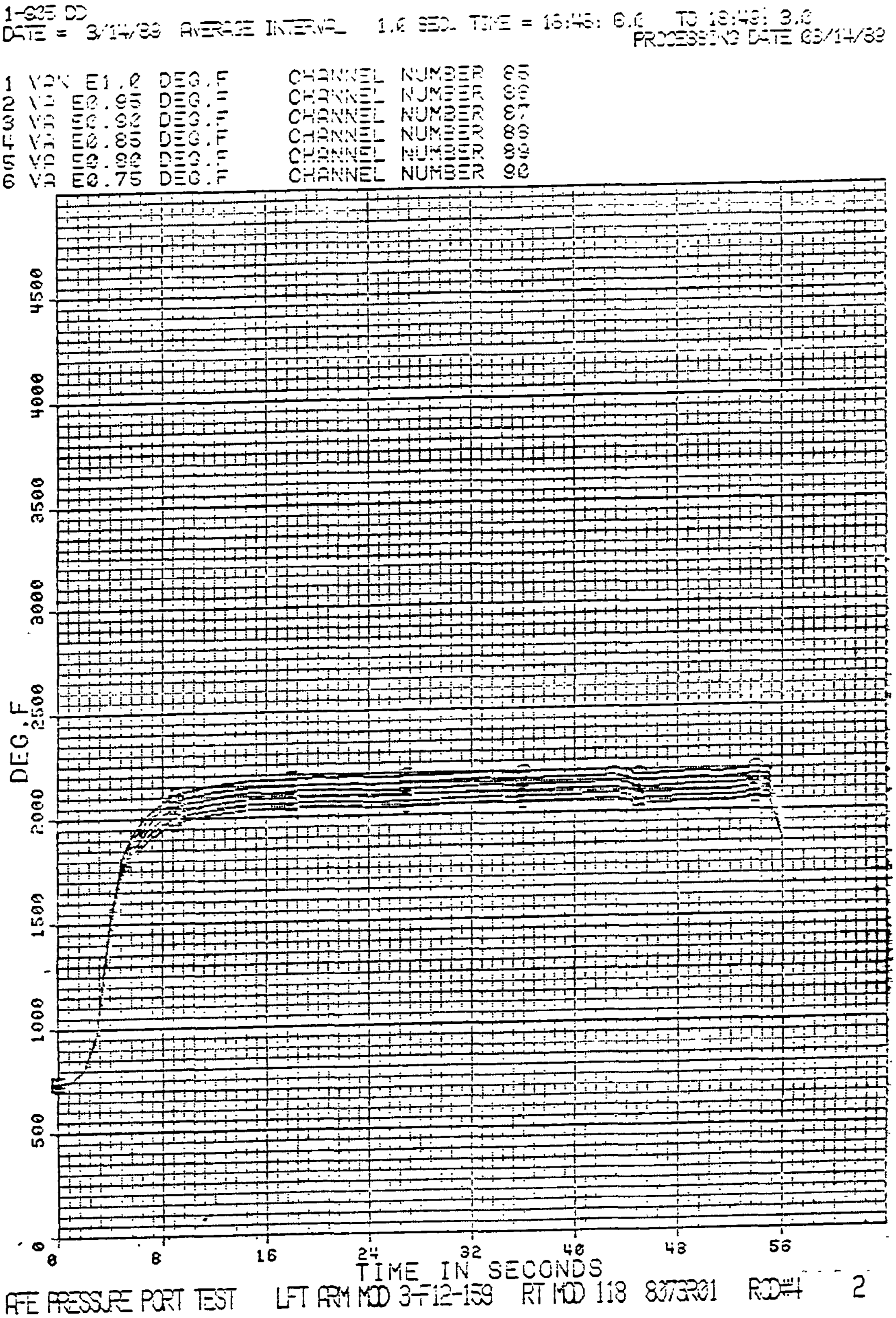
1-924 DD
DATE = 3/13/89 AVERAGE INTERVAL 1.0 SEC TIME = 23:40:35.1 TO 23:43: 8.1
PROCESSING DATE 03/14/89

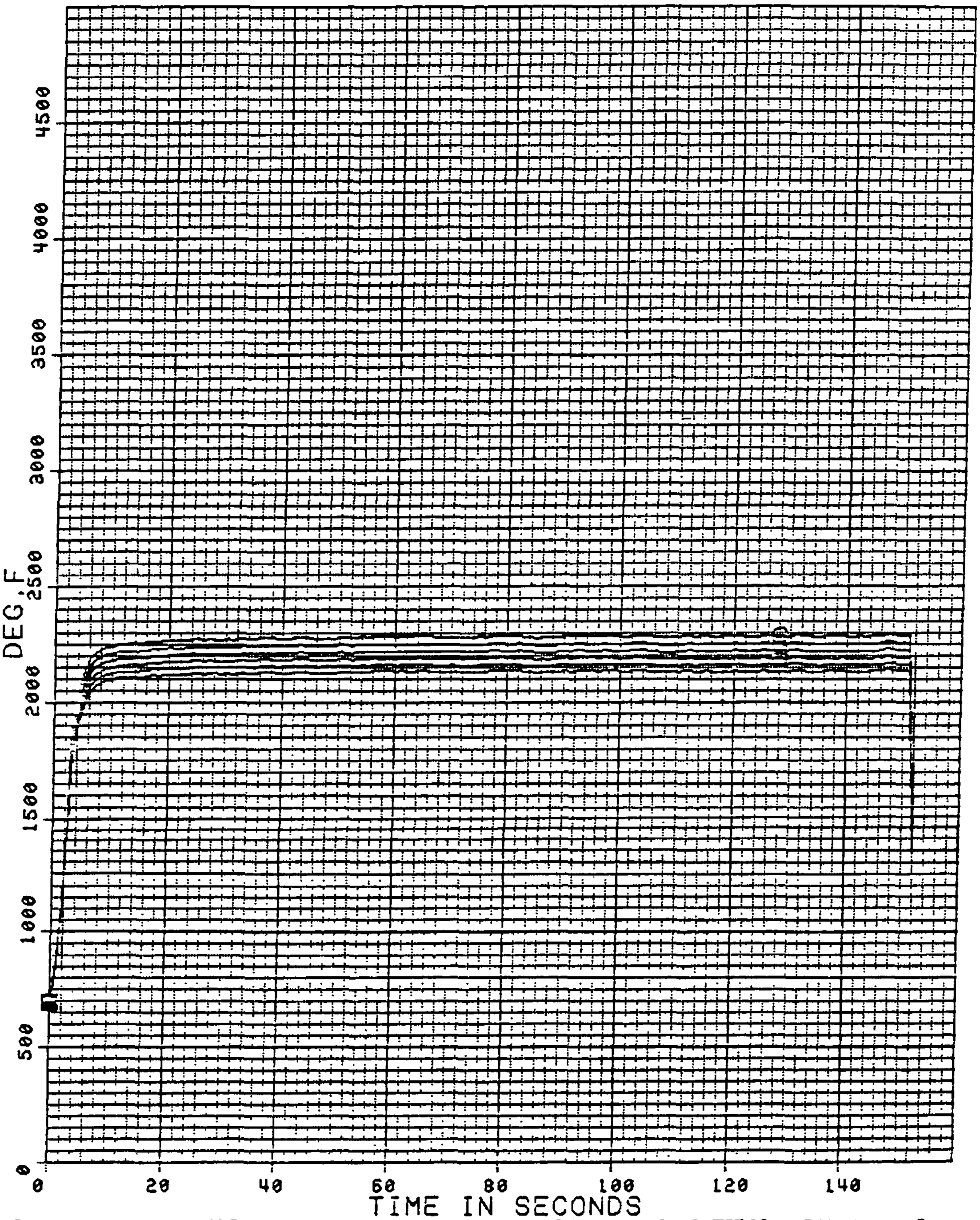
1 VAN E1.0 DEG.F CHANNEL NUMBER 85
2 VA E0.95 DEG.F CHANNEL NUMBER 86
3 VA E0.90 DEG.F CHANNEL NUMBER 87
4 VA E0.85 DEG.F CHANNEL NUMBER 88
5 VA E0.80 DEG.F CHANNEL NUMBER 89
6 VA E0.75 DEG.F CHANNEL NUMBER 90




1-935 DD
DATE = 3/14/89 AVERAGE INTERVAL 1.0 SEC. TIME = 16:46: 0.0 TO 16:48: 3.0
PROCESSING DATE 03/14/89
1 V2N E1.0 DEG.F CHANNEL NUMBER 85
2 V2 E0.95 DEG.F CHANNEL NUMBER 86
3 V3 E0.90 DEG.F CHANNEL NUMBER 87
4 V3 E0.85 DEG.F CHANNEL NUMBER 88
5 V3 E0.80 DEG.F CHANNEL NUMBER 89
6 V3 E0.75 DEG.F CHANNEL NUMBER 90
DEG.F
0
500
1000
1500
2000
2500
3000
3500
4000
4500
0
8
16
24
32
40
48
56
TIME IN SECONDS
AFE PRESSURE PORT TEST LFT ARM MOD 3-F12-159 RT MOD 118 8073R01 ROD#4 2

1-906 DD
DATE = 3/14/89 AVERAGE INTERVAL 1.0 SEC TIME = 21:29:15.0 TO 21:31:48.0
PROCESSING DATE 03/14/89

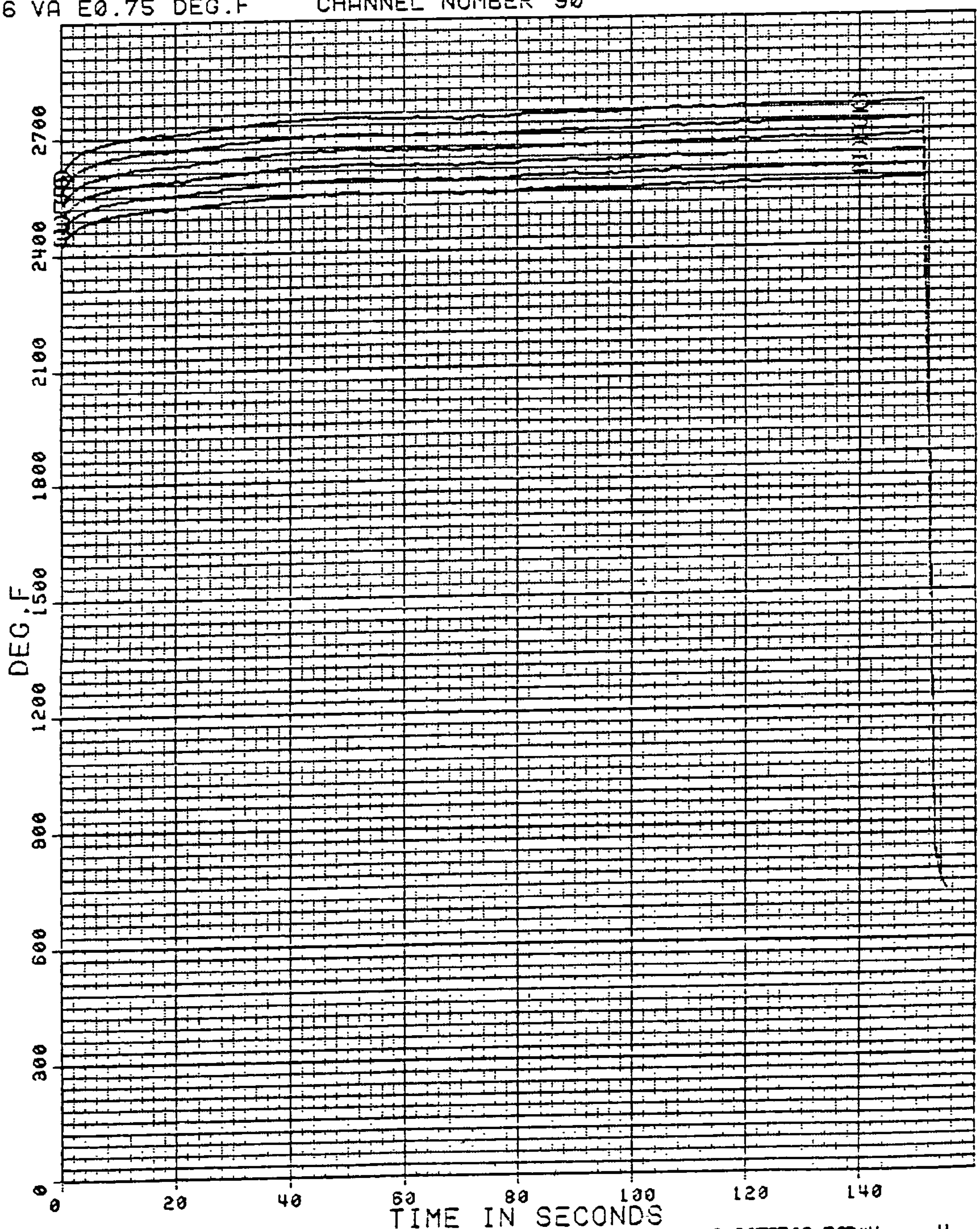
1 VAN E1.0 DEG.F CHANNEL NUMBER 85
2 VA E0.95 DEG.F CHANNEL NUMBER 86
3 VA E0.90 DEG.F CHANNEL NUMBER 87
4 VA E0.85 DEG.F CHANNEL NUMBER 88
5 VA E0.80 DEG.F CHANNEL NUMBER 89
6 VA E0.75 DEG.F CHANNEL NUMBER 90



AFE PRESSURE PORT TEST RERUN LF ARM 2-L9-162 / RT MOD 118 8073R02 RCD#4 2

1-907 DD
DATE = 3/14/89 AVERAGE INTERVAL 1.0 SEC TIME = 23:10: 6.0 TO 23:12:42.0
PROCESSING DATE 03/15/89

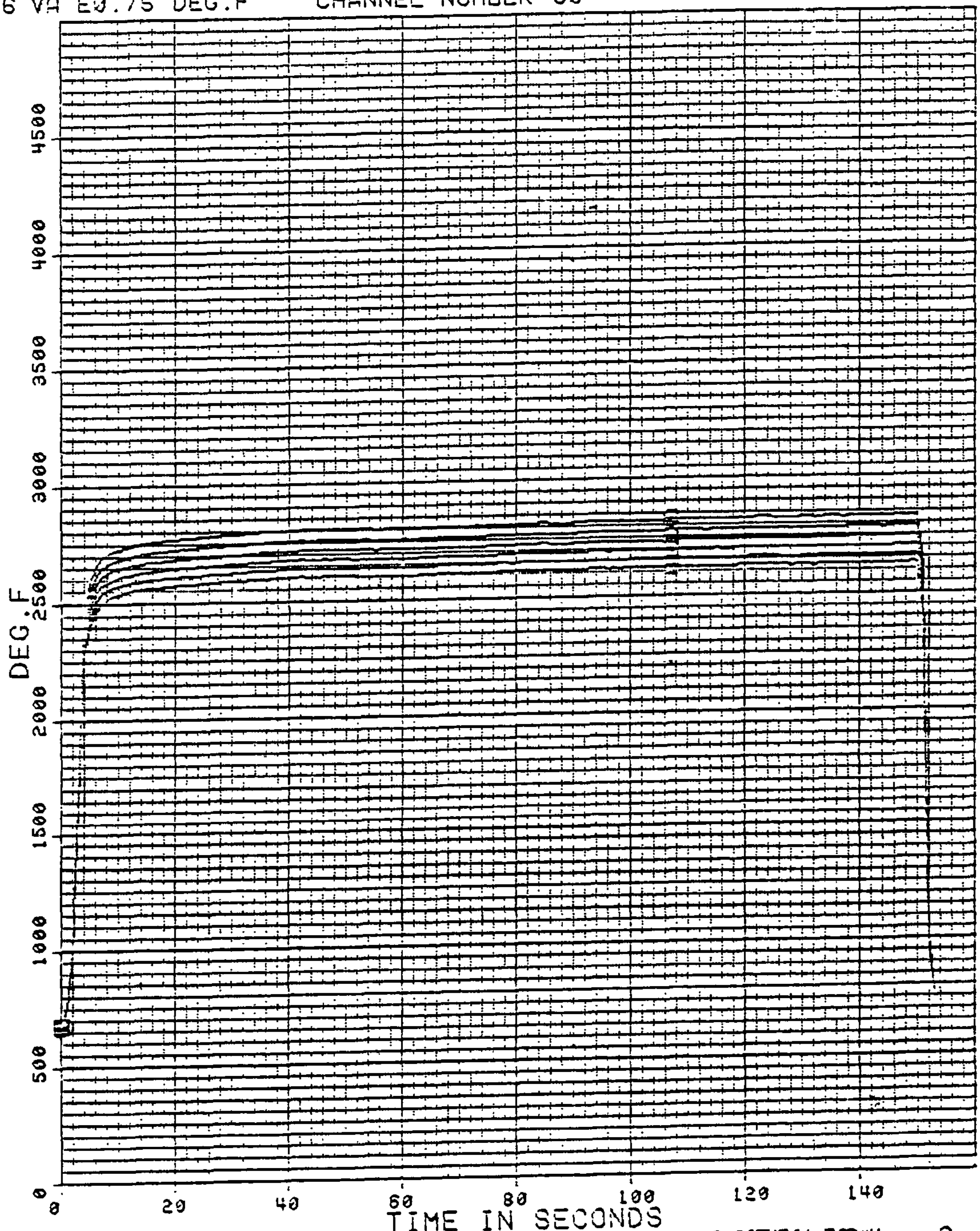
1 VAN E1.0 DEG.F CHANNEL NUMBER 85
2 VA E0.95 DEG.F CHANNEL NUMBER 86
3 VA E0.90 DEG.F CHANNEL NUMBER 87
4 VA E0.85 DEG.F CHANNEL NUMBER 88
5 VA E0.80 DEG.F CHANNEL NUMBER 89
6 VA E0.75 DEG.F CHANNEL NUMBER 90



AFF PRESSURE PORT TEST LFT ARM MOD 3-F12-159 SEQ 3 RT MOD 118 9073R03 ROTHILL U

1-923-CD
DATE = 3/15/89 AVERAGE INTERVAL 1.0 SEC TIME = 21:50:26.0 TO 21:53: 0.0
PROCESSING DATE 03/15/89

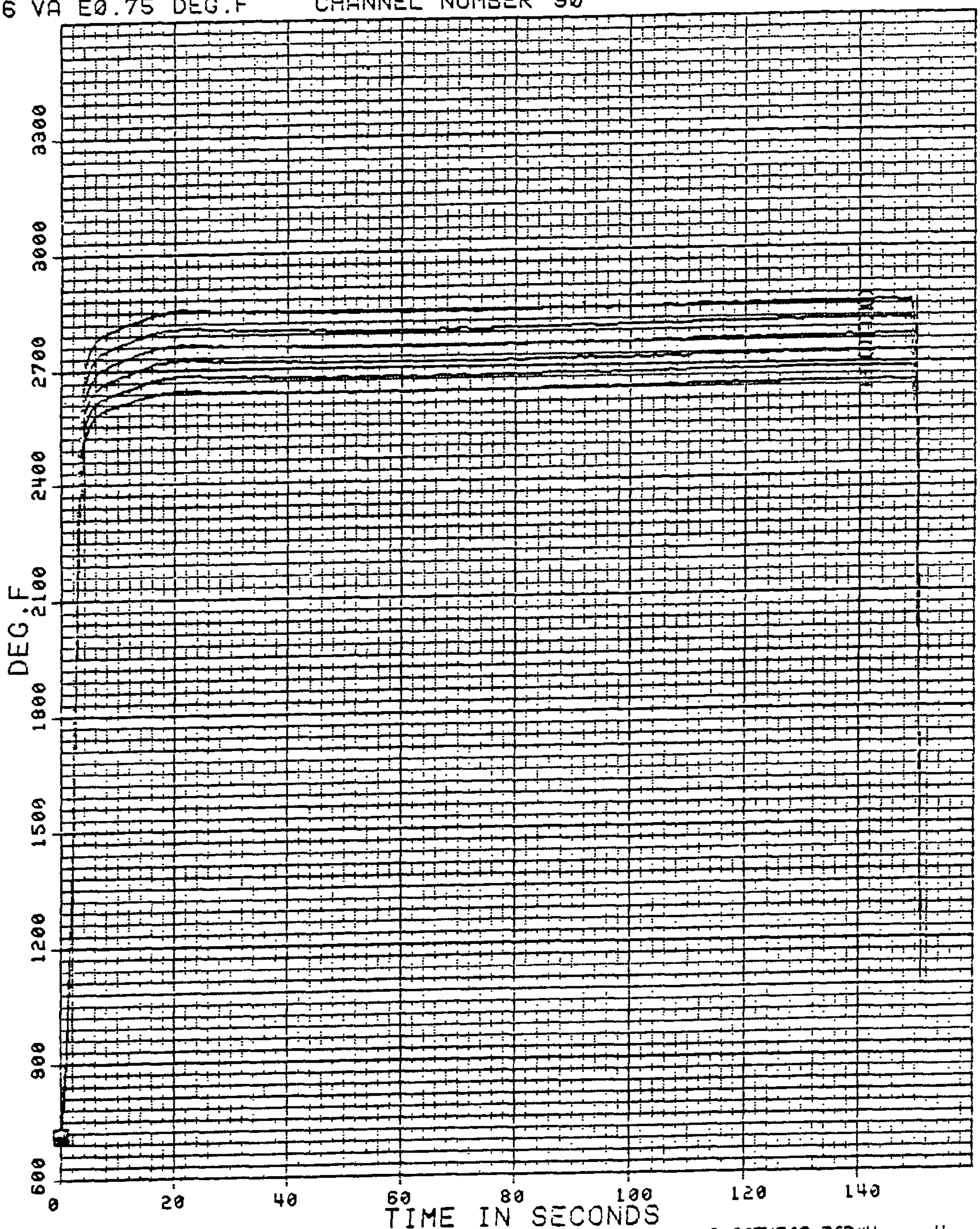
1 VAN E1.0 DEG.F CHANNEL NUMBER 85
2 VA E0.95 DEG.F CHANNEL NUMBER 86
3 VA E0.90 DEG.F CHANNEL NUMBER 87
4 VA E0.85 DEG.F CHANNEL NUMBER 88
5 VA E0.80 DEG.F CHANNEL NUMBER 89
6 VA E0.75 DEG.F CHANNEL NUMBER 90



AFE PRESSURE PORT TEST LFT ARM MOD 5-F12-161 SEQ 4 RT MOD 118 S074R01 ROD#1 2

1-929-DD
DATE = 3/15/89 AVERAGE INTERVAL 1.0 SEC TIME = 23: 2: 6.9 TO 23: 4:38.9
PROCESSING DATE 03/16/89

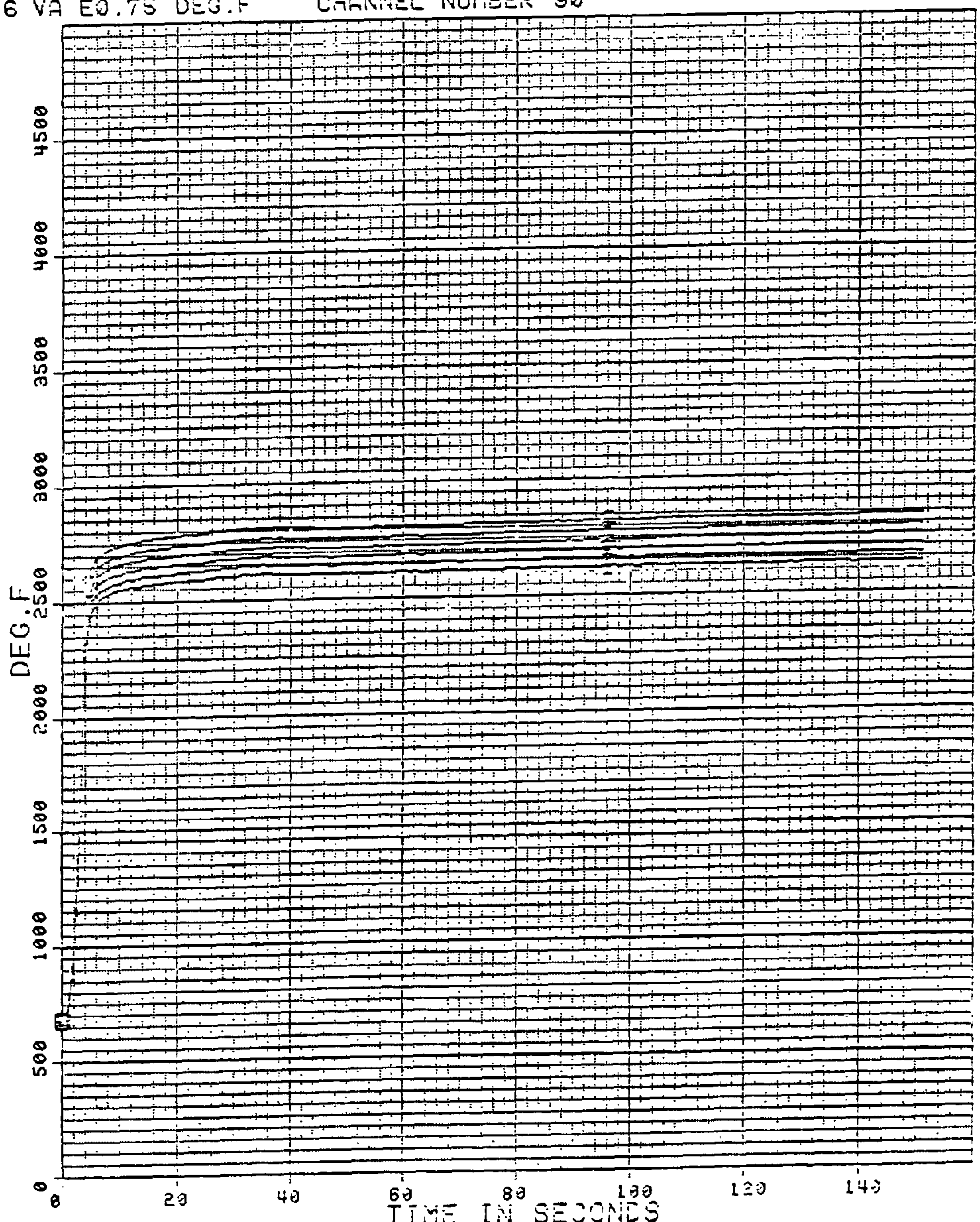
1 VAN E1.0 DEG.F CHANNEL NUMBER 85
2 VA E0.95 DEG.F CHANNEL NUMBER 86
3 VA E0.90 DEG.F CHANNEL NUMBER 87
4 VA E0.85 DEG.F CHANNEL NUMBER 88
5 VA E0.80 DEG.F CHANNEL NUMBER 89
6 VA E0.75 DEG.F CHANNEL NUMBER 90



AFE PRESSURE PORT TEST LFT ARM MOD 4-F12FB-160 SQ 5/RT MOD 118 9074R02 RCD#4 4

1-910-DD
DATE = 3/16/89 AVERAGE INTERVAL 1.0 SEC TIME = 21:45:11.1 TO 21:47:43.1
PROCESSING DATE 03/16/89

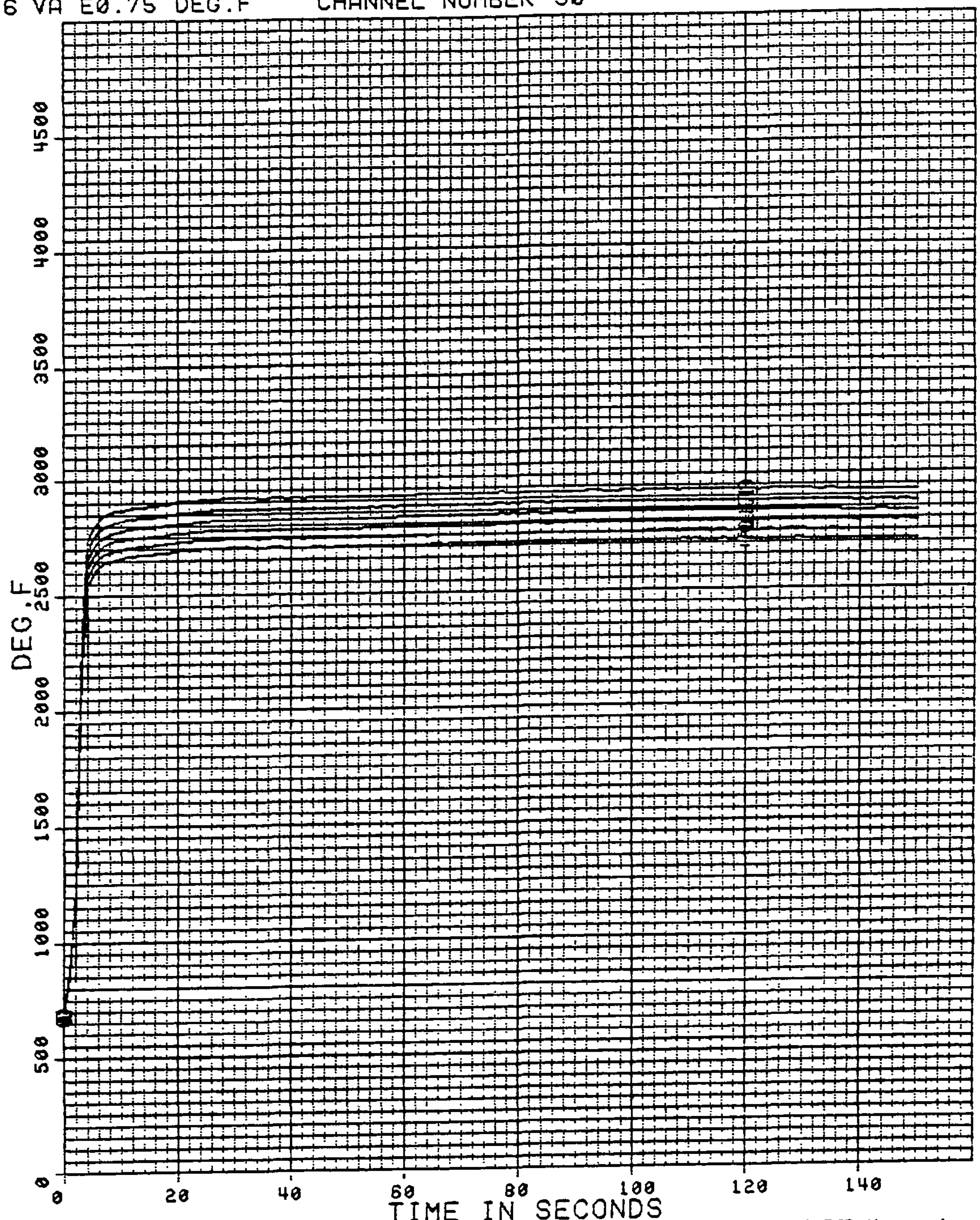
1 VAN E1.0 DEG.F CHANNEL NUMBER 85
2 VA E0.95 DEG.F CHANNEL NUMBER 86
3 VA E0.90 DEG.F CHANNEL NUMBER 87
4 VA E0.85 DEG.F CHANNEL NUMBER 88
5 VA E0.80 DEG.F CHANNEL NUMBER 89
6 VA E0.75 DEG.F CHANNEL NUMBER 90



AFE PRESSURE PORT TEST LFT ARM MOD 3-F12-164 SEQ 6 RT MOD 118 S07AR02 ROD#4 1

1-911-DD
DATE = 3/16/89 AVERAGE INTERVAL 1.0 SEC TIME = 23:12:18.0 TO 23:14:49.0
PROCESSING DATE 03/16/89

1 VAN E1.0 DEG.F CHANNEL NUMBER 85
2 VA E0.95 DEG.F CHANNEL NUMBER 86
3 VA E0.90 DEG.F CHANNEL NUMBER 87
4 VA E0.85 DEG.F CHANNEL NUMBER 88
5 VA E0.80 DEG.F CHANNEL NUMBER 89
6 VA E0.75 DEG.F CHANNEL NUMBER 90



AFE PRESSURE PORT TEST LFT ARM MOD 7-L22-163 SEQ 8 RT MOD 118 8074R02 ROD#4 1

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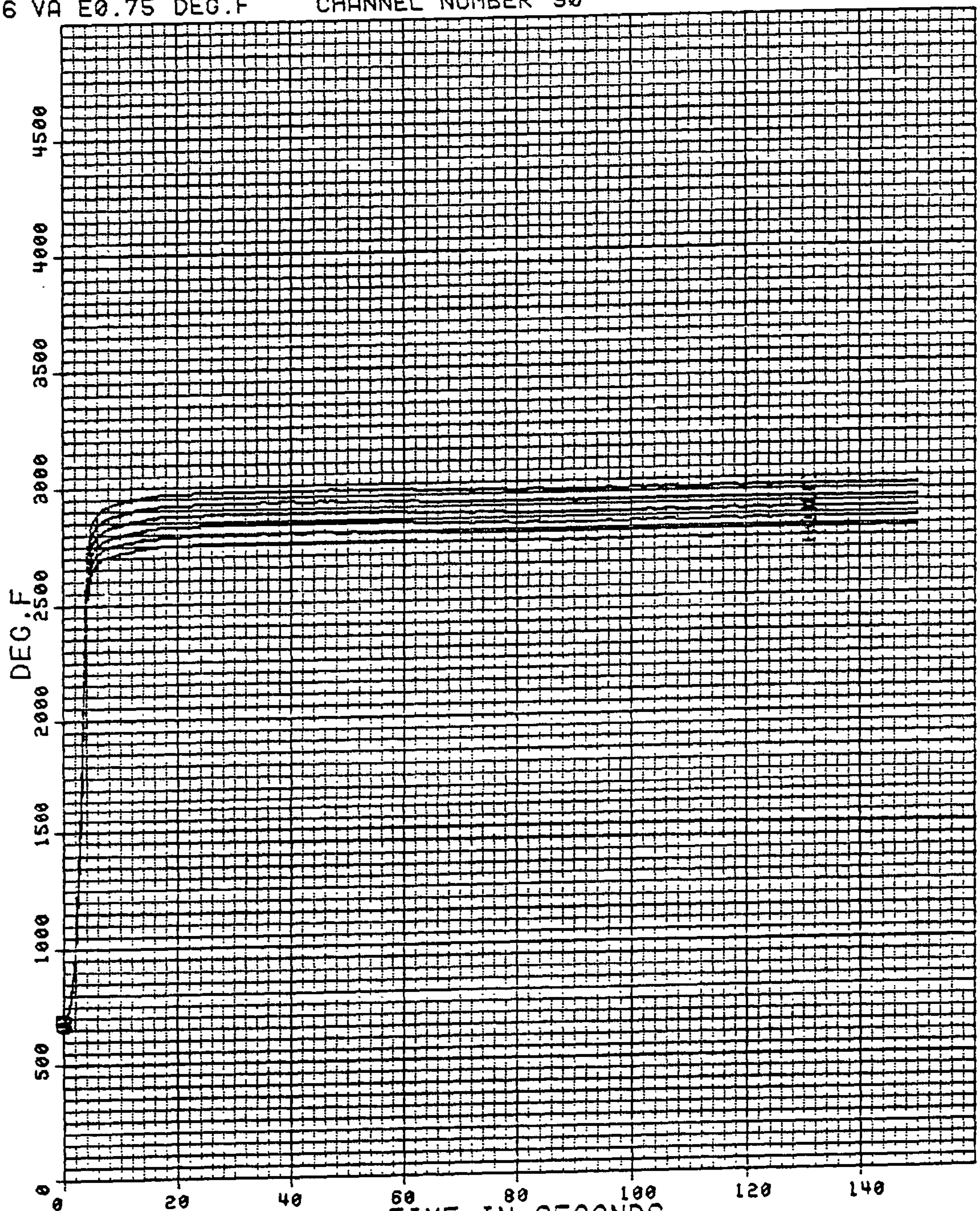
OF POOR QUALITY

1-912-DD
DATE = 3/17/89 AVERAGE INTERVAL 1.0 SEC TIME = 22:46:56.2 TO 22:49:27.2
PROCESSING DATE 03/18/89

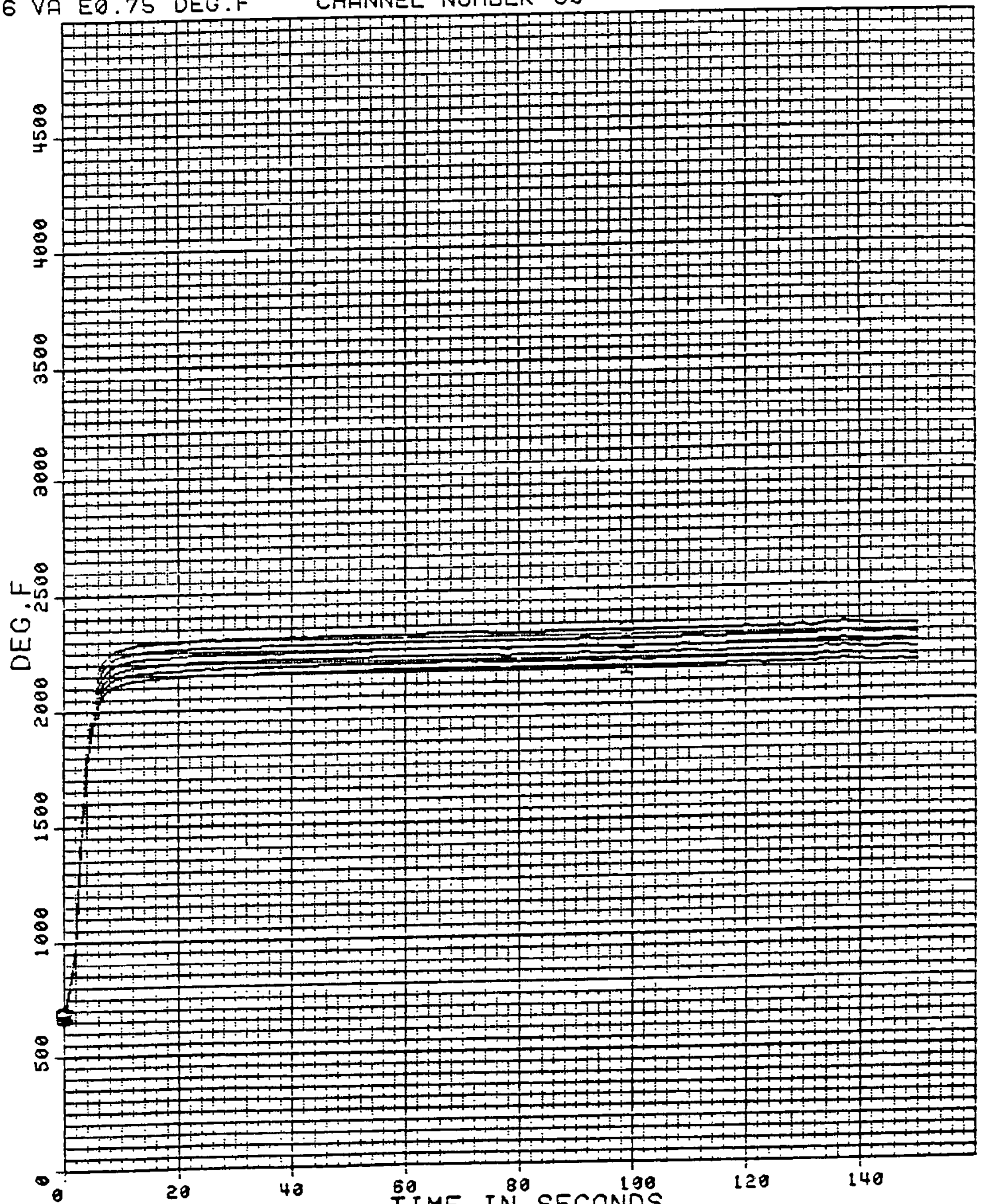
1 VAN E1.0 DEG.F CHANNEL NUMBER 85
2 VA E0.95 DEG.F CHANNEL NUMBER 86
3 VA E0.90 DEG.F CHANNEL NUMBER 87
4 VA E0.85 DEG.F CHANNEL NUMBER 88
5 VA E0.80 DEG.F CHANNEL NUMBER 89
6 VA E0.75 DEG.F CHANNEL NUMBER 90



AFE PRESS PORT TEST LFT ARM MOD 2-L22-158 SG7 /RT MOD 1-L9FB-157 807GR2 ROD#4 2

1-913-DD
DATE = 3/17/89 AVERAGE INTERVAL 1.0 SEC TIME = 23: 9:29.0 TO 23:12: 0.0
PROCESSING DATE 03/17/89

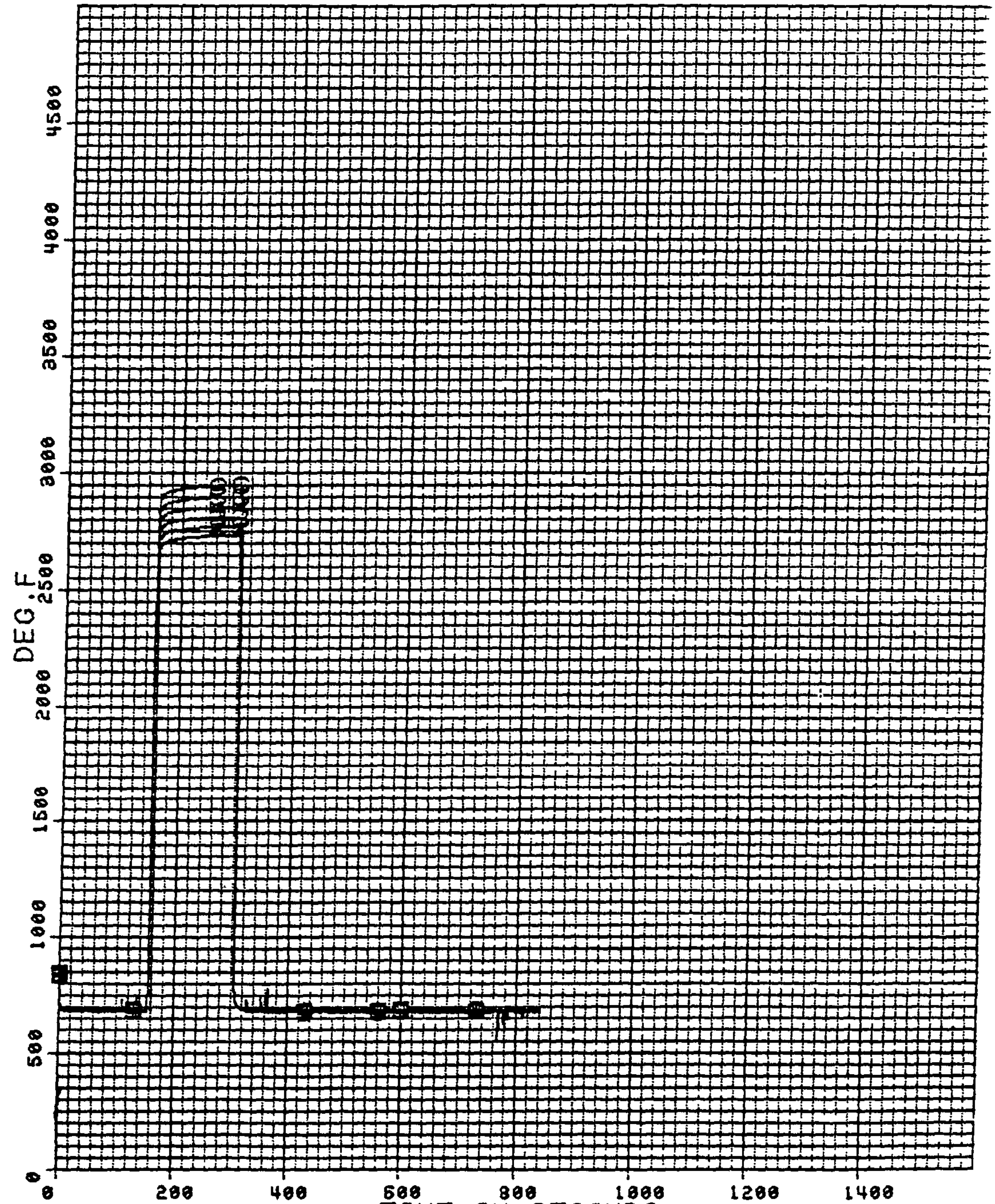
1 VAN E1.0 DEG.F CHANNEL NUMBER 85
2 VA E0.95 DEG.F CHANNEL NUMBER 86
3 VA E0.90 DEG.F CHANNEL NUMBER 87
4 VA E0.85 DEG.F CHANNEL NUMBER 88
5 VA E0.80 DEG.F CHANNEL NUMBER 89
6 VA E0.75 DEG.F CHANNEL NUMBER 90



AFE PRESS PORT TEST LFT ARM MOD 2-L22-158 /RT MOD 1-LSFB-157 SQ1 8076R2 RCD#4 2

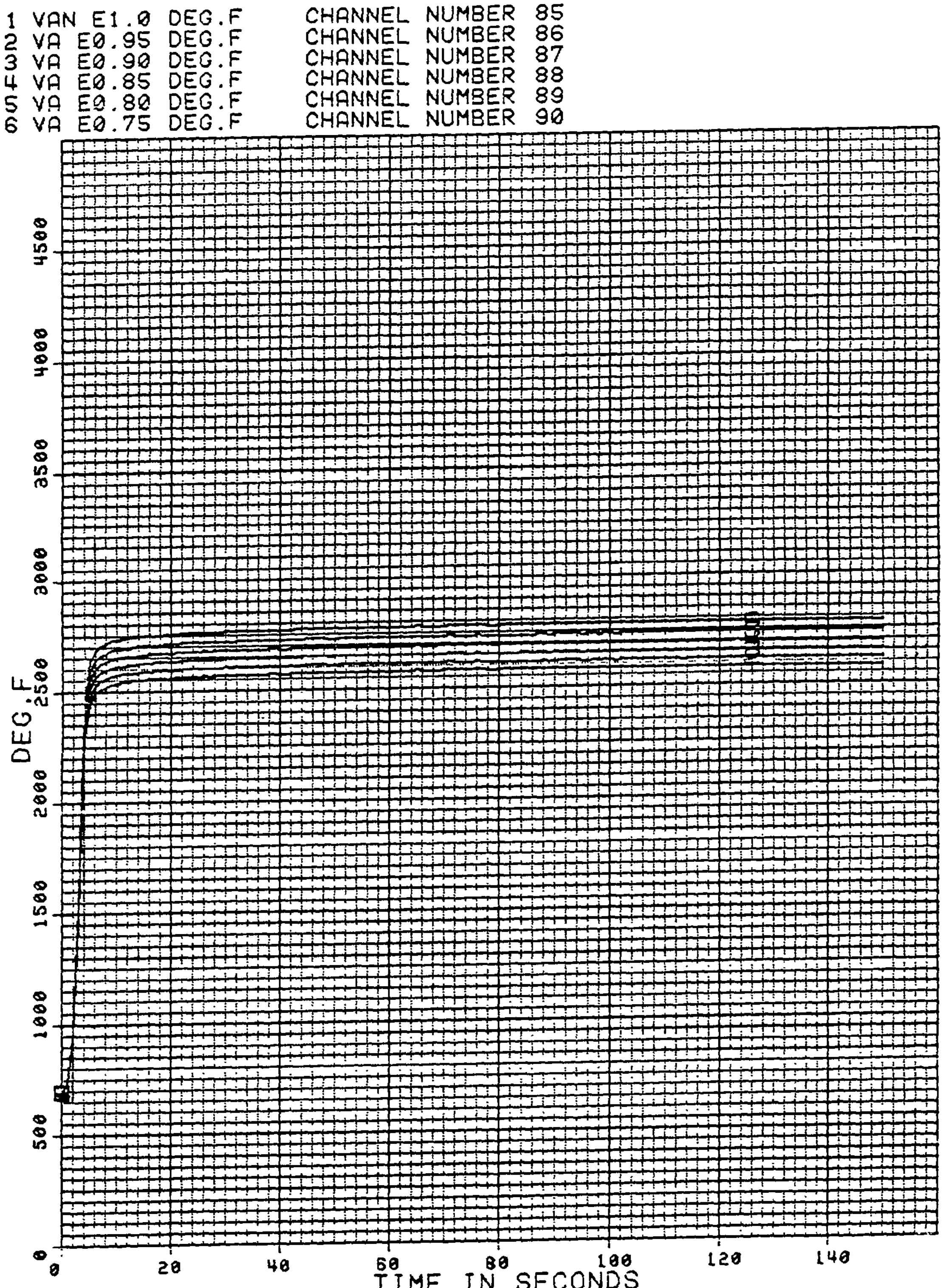
1-914-DD
DATE = 3/22/89 AVERAGE INTERVAL 1.0 SEC TIME = 17:20:50.1 TO 17:34:46.1
PROCESSING DATE 03/22/8

1 VAN E1.0 DEG.F CHANNEL NUMBER 85
2 VA E0.95 DEG.F CHANNEL NUMBER 86
3 VA E0.90 DEG.F CHANNEL NUMBER 87
4 VA E0.85 DEG.F CHANNEL NUMBER 88
5 VA E0.80 DEG.F CHANNEL NUMBER 89
6 VA E0.75 DEG.F CHANNEL NUMBER 90



OVERTEST OF MOD 2-L22FB-158 IN LT ARM / ALUM IMPINGEMENT PLATE 8081R01 ROD#4 3

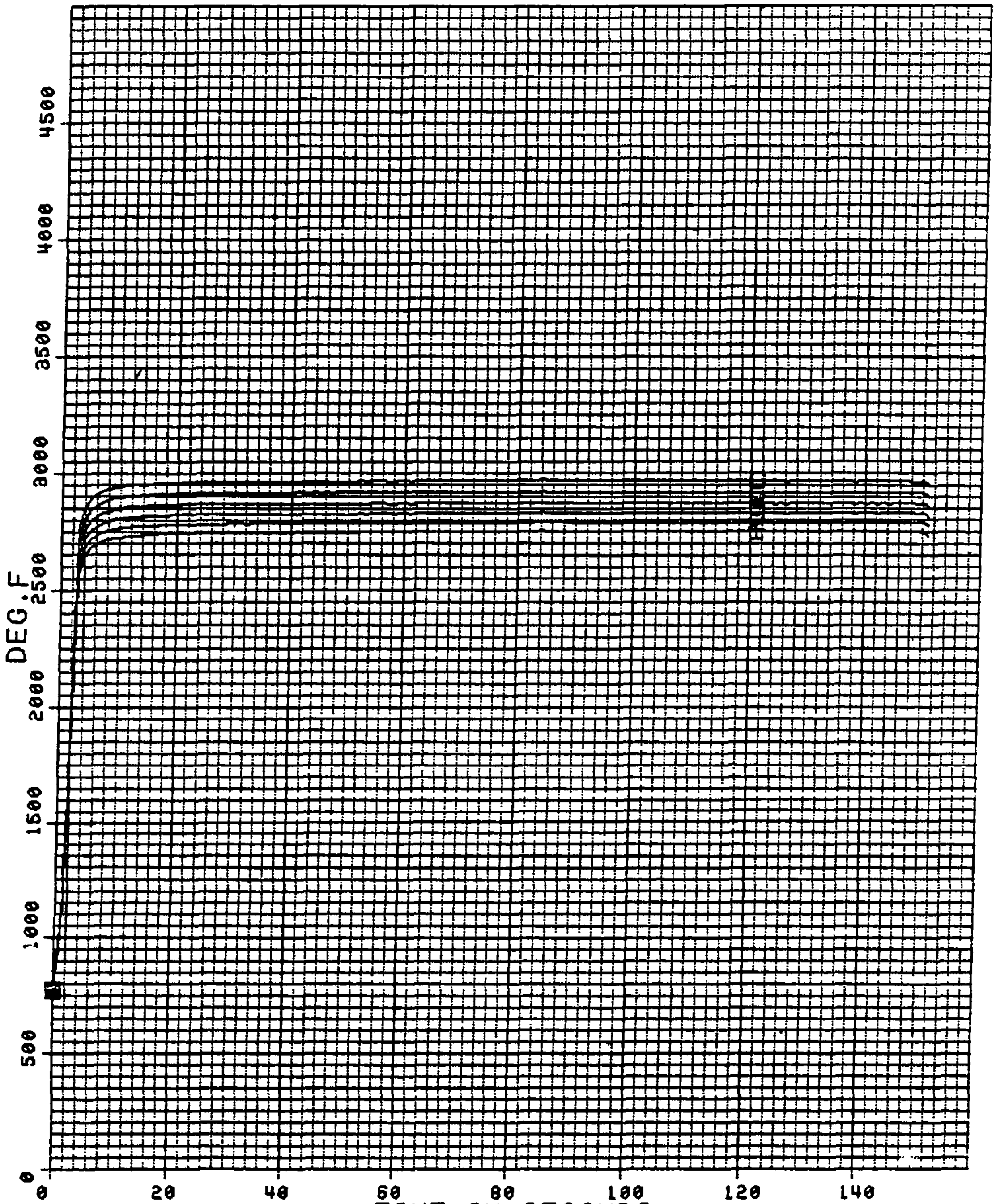
1-915-DD
DATE = 3/22/89 AVERAGE INTERVAL 1.0 SEC TIME = 18:38:49.1 TO 18:41:20.1
PROCESSING DATE 03/22/89



OVERTEST OF MOD 8-F12-164 IN RT ARM Z=10 2700 DEG.F 150 SEC 8081R02 ROD#4 4

1-916-DD
DATE = 3/22/89 AVERAGE INTERVAL 1.0 SEC TIME = 23: 0:44.1 TO 23: 3:16.1
PROCESSING DATE 03/23/89

1 VAN E1.0 DEG.F CHANNEL NUMBER 85
2 VA E0.95 DEG.F CHANNEL NUMBER 86
3 VA E0.90 DEG.F CHANNEL NUMBER 87
4 VA E0.85 DEG.F CHANNEL NUMBER 88
5 VA E0.80 DEG.F CHANNEL NUMBER 89
6 VA E0.75 DEG.F CHANNEL NUMBER 90



OVERTEST OF MOD 7-L22-163 IN LFT ARM ALUM IMPINGEMENT PLATE 8081R03 ROD #4 3

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At JSC on May 15, 1989, at Base Flow Heating Experiment Preliminary Design Review
Langley Contract Monitor: John W. Cox

16. Abstract
This program objectives were to produce a pressure measurements system that penetrates the thermal protection system of a spacecraft and able to obtain accurate pressure data. The design was tested vibro-acoustically, aerothermally, and structurally and found to be adequate. This design is a possible replacement of the current pressure system on the orbiter; and the aero-thermal test may be of interest to AFE experiments other than PD/ADS.

17. Key Words (Suggested by Author(s))
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Aero-Thermal Performance

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